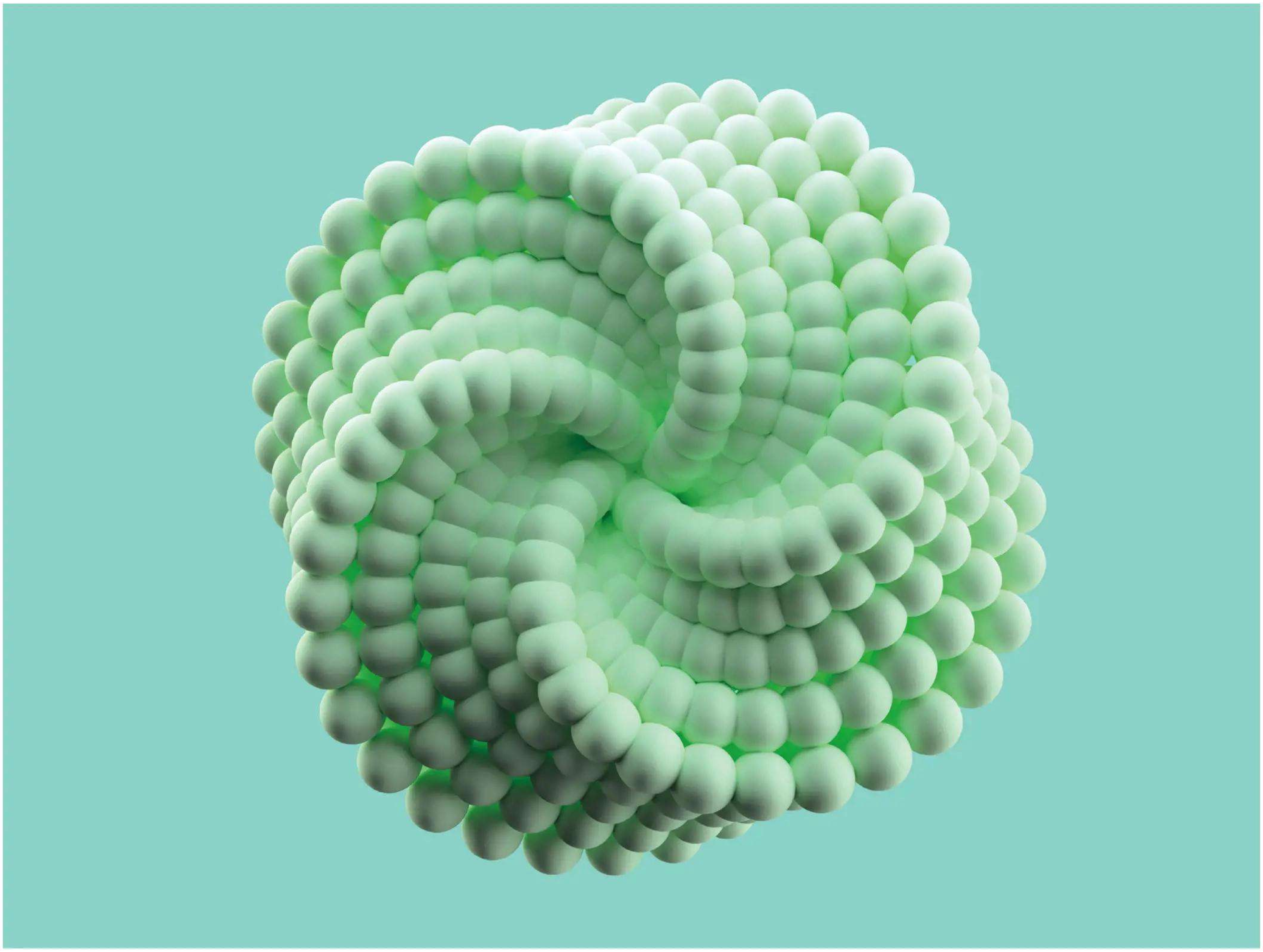
NEW

THE Science COLLECTION

THE TRUTH ABOUT DARK MATTER
ARE WE STILL EVOLVING?
HOW TO SAVE THE WORLD
A GUIDE TO THE GALAXY
THE SCIENCE BEHIND EMOTIONS
SPENDING A YEAR ON MARS

Digital Edition

FUTURE
FOURTH EDITION



Welcome

An asteroid is hurtling towards Earth. We have 72 hours to prepare for impact – what do we do? What about green power; is there a way we can harness it to save the world? And how do forensic scientists help solve crimes?

The answers to these questions and many more lie in the pages of The Science Collection. Find out if the human race is still evolving, take a deep dive into the brain, and explore some of the most amazing habitats on Earth before heading out into the universe. It all begins just over the page.

FUTURE

THE
Science
COLLECTION

Future PLC Quay House, The Ambury, Bath, BA1 1UA

Editorial
Editor **Katharine Marsh**
Designer **Andy Downes**
Compiled by **Jacqueline Snowden & Katy Stokes**
Head of Art & Design **Greg Whitaker**
Editorial Director **Jon White**
Managing Director **Grainne McKenna**

Cover images
Getty Images

Photography
All copyrights and trademarks are recognised and respected

Advertising
Media packs are available on request
Commercial Director **Clare Dove**

International
Head of Print Licensing **Rachel Shaw**
licensing@futurenet.com
www.futurecontenthub.com

Circulation
Head of Newstrade **Tim Mathers**

Production
Head of Production **Mark Constance**
Production Project Manager **Matthew Eglinton**
Advertising Production Manager **Joanne Crosby**
Digital Editions Controller **Jason Hudson**
Production Managers **Keely Miller, Nola Cokely, Vivienne Calvert, Fran Twentyman**

Printed in the UK

Distributed by Marketforce – www.marketforce.co.uk
For enquiries, please email: mfcommunications@futurenet.com

The Science Collection Fourth Edition (HIB6202)

FUTURE

Connectors.
Creators.
Experience
Makers.

Future plc is a public company quoted on the London Stock Exchange (symbol: FUTR)
www.futureplc.com

Chief Executive Officer **Jon Steinberg**
Non-Executive Chairman **Richard Huntingford**
Chief Financial and Strategy Officer **Penny Ladkin-Brand**

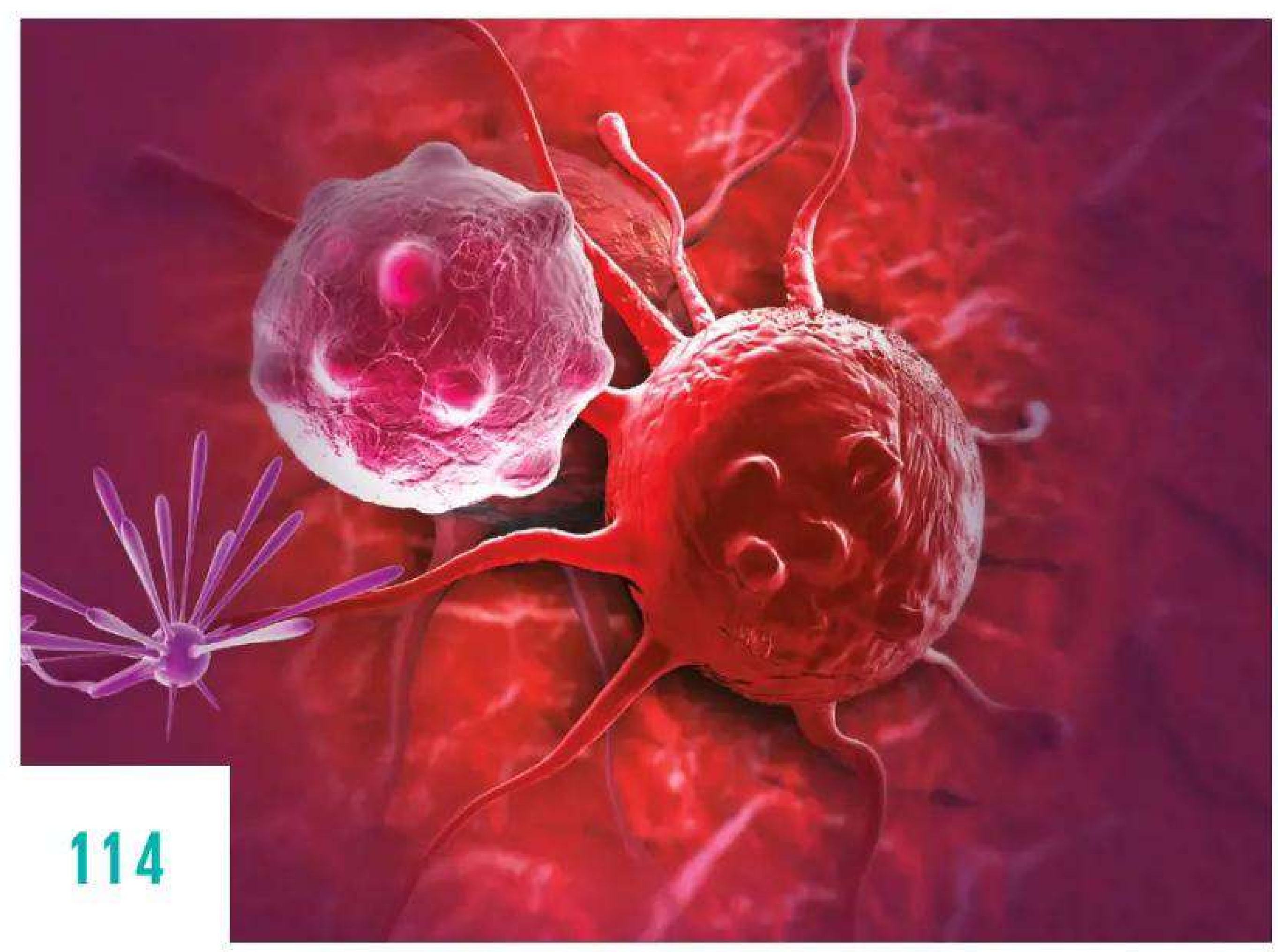
Tel +44 (0)1225 442 244

Widely Recycled

ipso. For press freedom with responsibility

Contents

68



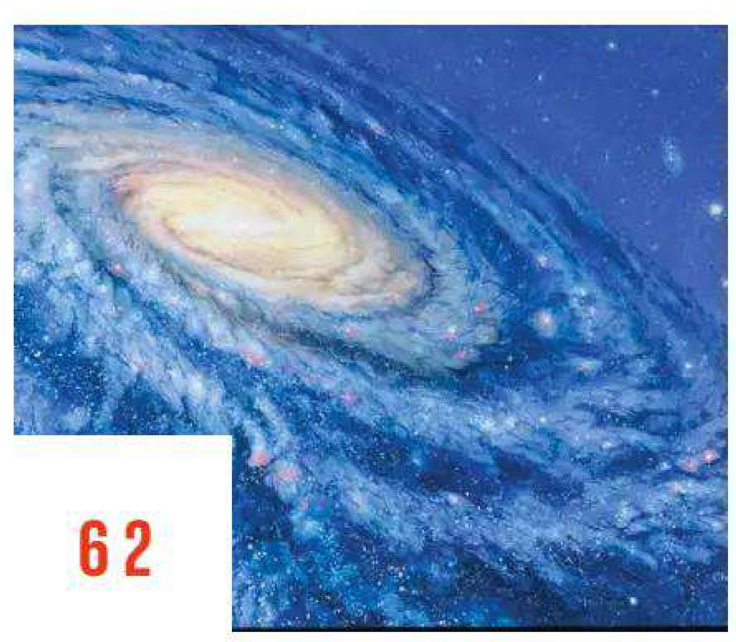
114

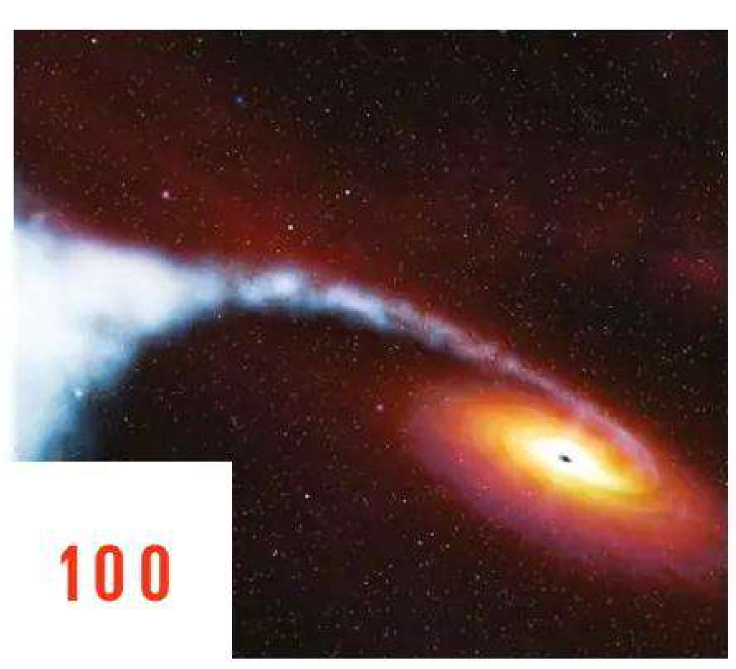
106


16

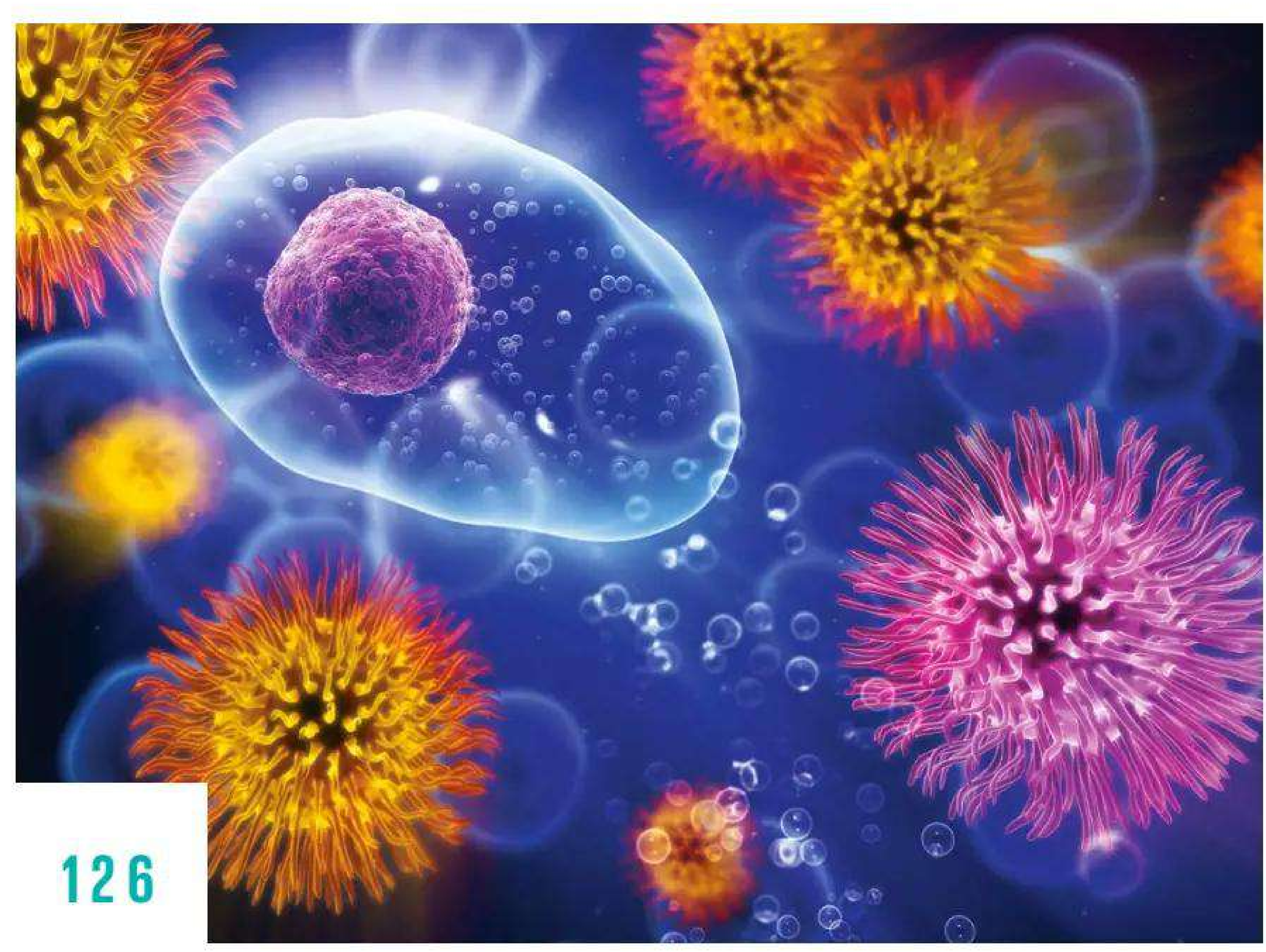

74


80


62


100

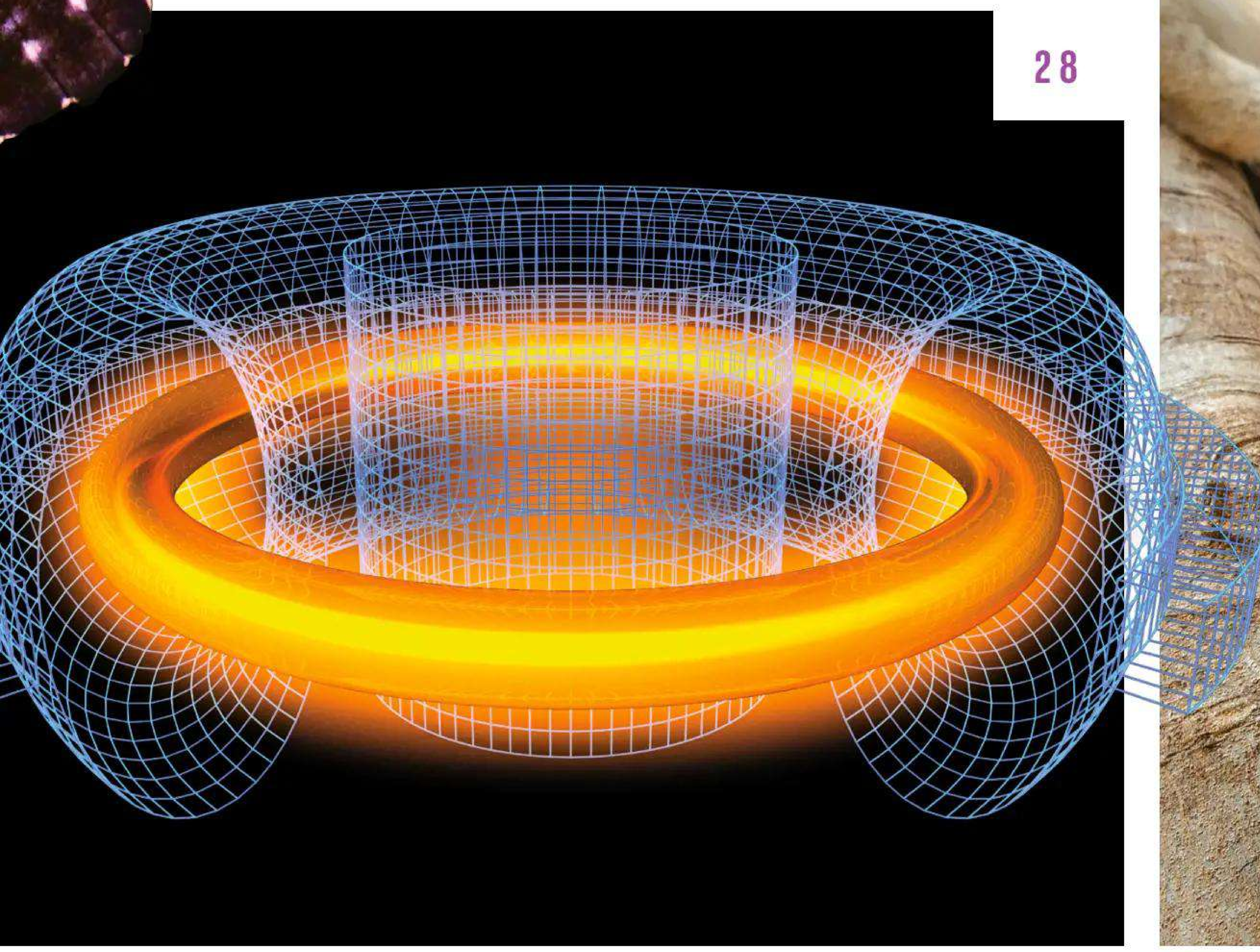
THE HUMAN BODY


126

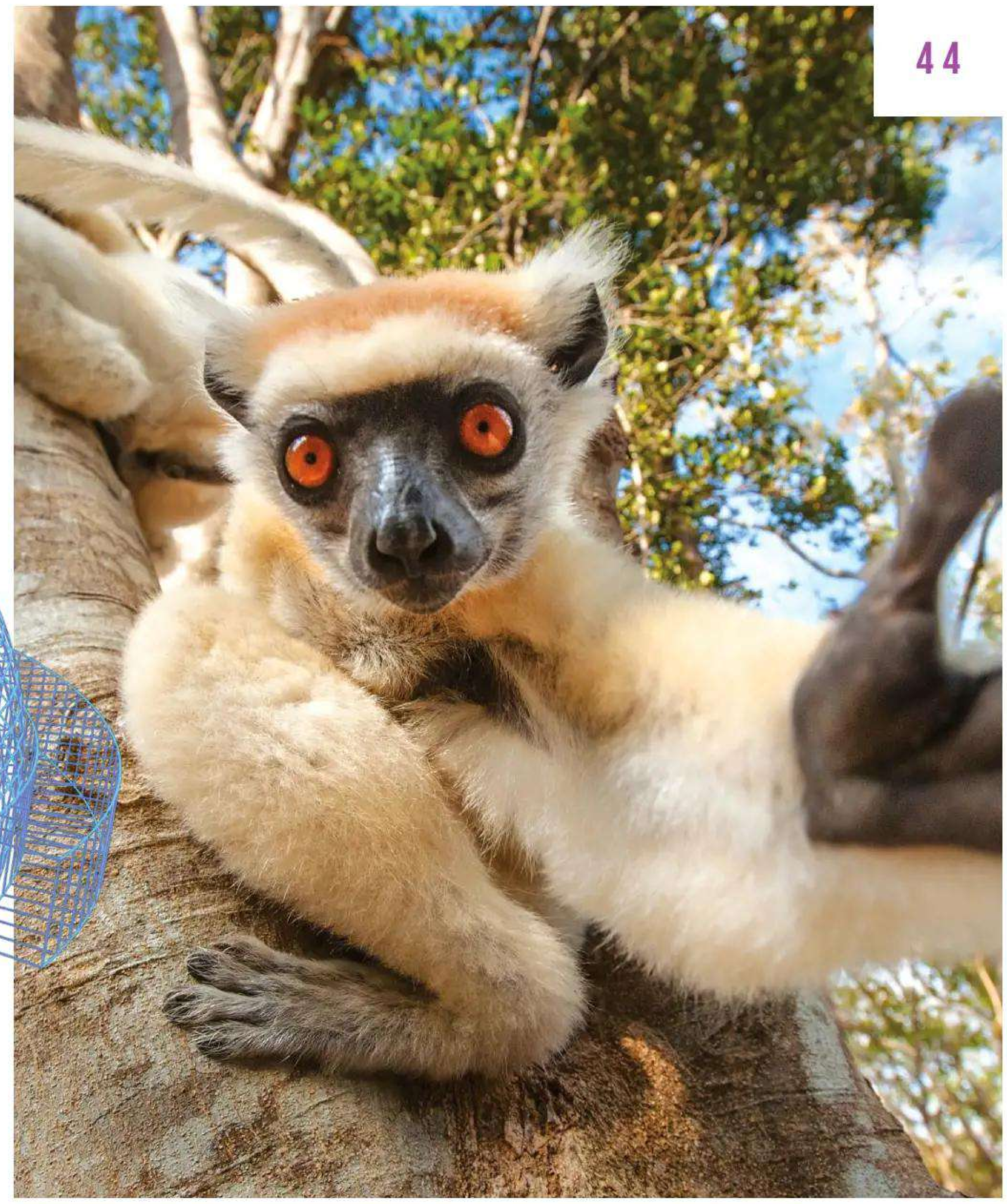
The World Around Us

38

10



28



44

52

22

16

How to save the world

Discover the incredible science and tech that will protect our planet

Humans only make up about one ten thousandth of the biomass on Earth, but our impact on the planet is drastically out of proportion to our numbers. In the last 250 years we have added over 400 billion tons of carbon to the atmosphere and approximately half of that has happened since the mid 1980s. No other organism in Earth's history has altered the environment so much so quickly.

It's not just the amount of pollution we produce, either; humans have invented entirely new kinds of pollution too. Polythene, chlorofluorocarbons, organophosphates and synthetic hormones didn't exist in the environment until humans created them. Other toxins, like heavy metals and radioactive isotopes, were only there in trace amounts until the industrial age found new ways to refine and concentrate them. These pollutants are toxic because they are too new for life to have evolved a way of dealing with them, which means they don't get broken down either.

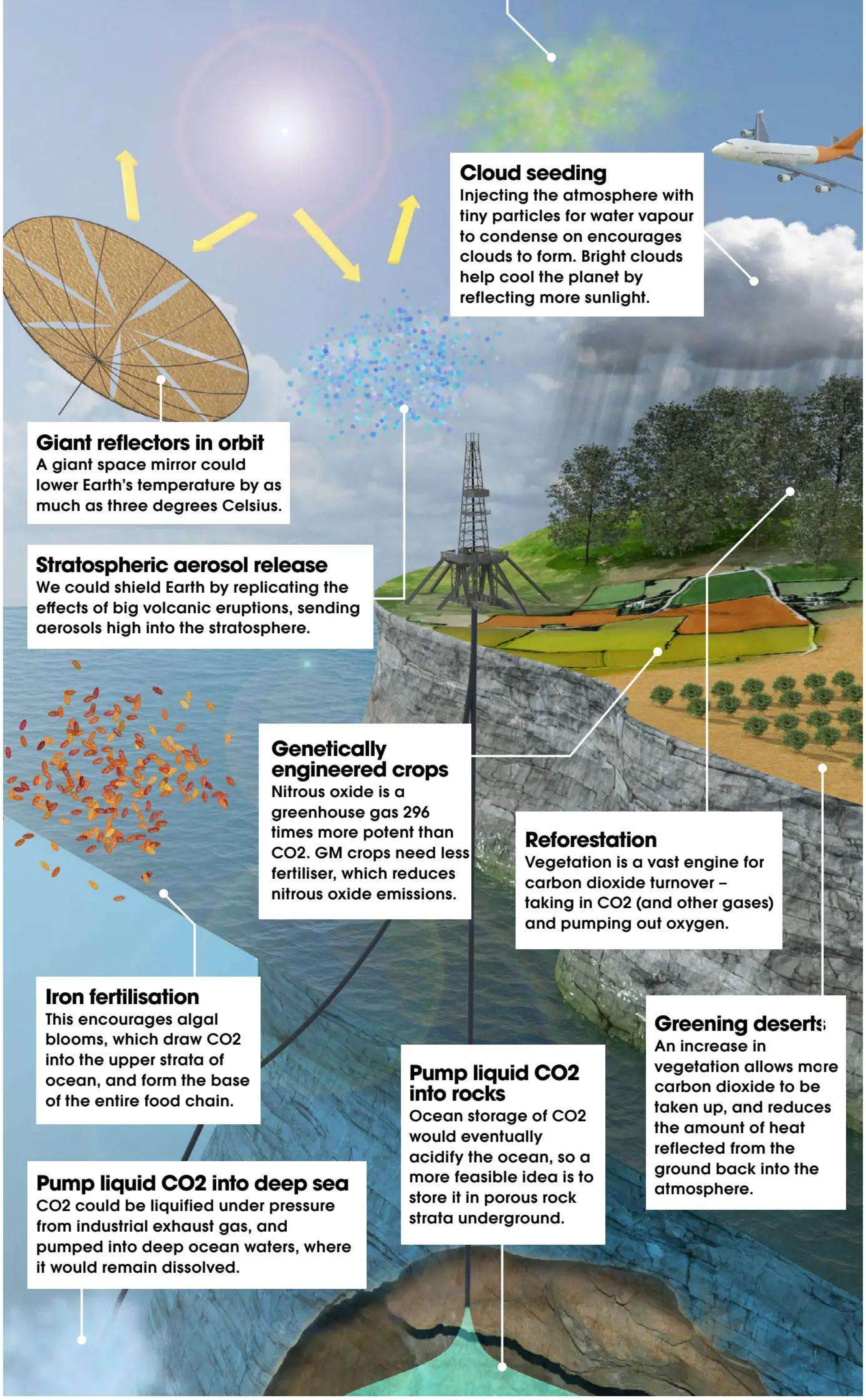
A 2020 study analysed the frozen and canned fish from grocery stores in Bosnia and Herzegovina. It found the heavy metals mercury and cadmium in 100 per cent of sampled fish, such as European hake, Atlantic bluefin tuna and Atlantic mackerel. The study also found lead in 33 samples. The authors of the study advised that bluefin tuna and mackerel should be consumed in moderation due to their mercury content levels.

But pollution is entirely within our power to control. In 1952, the Great Smog of London killed an estimated 12,000 people over four days, but four years later the Clean Air Act was passed and air quality steadily improved. The countries that were once the biggest polluters have also been the first to introduce emissions standards. Just 50 years ago, New York City was plagued by a dense smog responsible for around 24 deaths per day, but air pollution legislation and incentives have helped to drastically improve the city's air quality. The Big Apple is even working towards achieving the cleanest air of any major US city by the year 2030.

The technological progress that created the pollution can also be harnessed to curb it. Cleaner fuels, more efficient engines, better recycling, and environmental clean-up technologies are all being developed to slow the rate at which humans are poisoning the planet. From huge, garbage-sucking machines in the ocean to neighbourhood recycling schemes, there is a way for everyone to help ensure that Earth's most polluted century is behind us.

Can we stop global warming?

While governments squabble over carbon emissions, innovative technology could help to slow temperature rises



Ground pollution

The toxic chemicals lurking beneath the surface of our poisoned planet

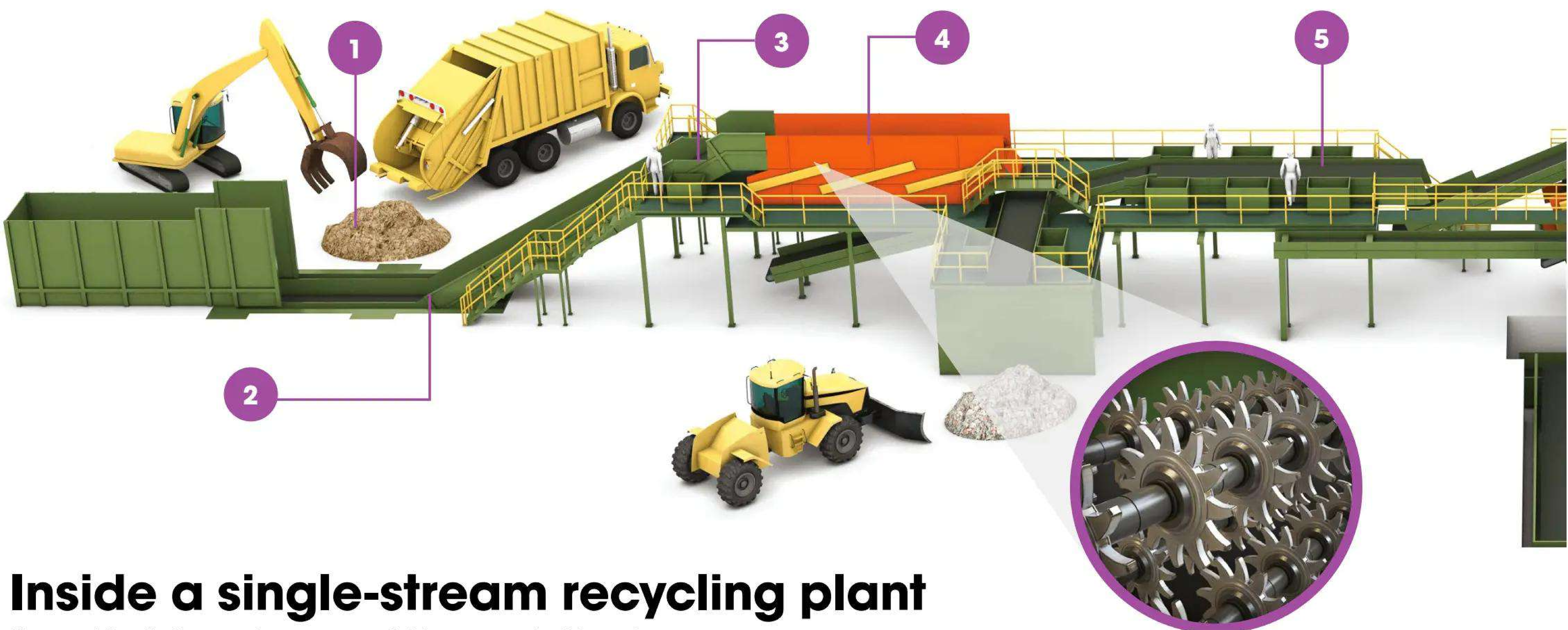
Land pollution isn't just about the space taken up by landfill. A city the size of New York could fit all of its rubbish for the next thousand years in a landfill 56 kilometres long by 56 kilometres wide. That sounds like a lot, but that's the waste of 2.5 per cent of Americans buried in just 0.03 per cent of the country's land area. And that land isn't gone forever – eventually a landfill site just becomes a grassy hill.

The real source of land pollution is all the other things that don't end up in landfill. Copper and aluminium mining generate huge piles of powdered rock (called 'tailings') left behind after the metal has been extracted. These tailings are high in toxic heavy metals, such as mercury and cadmium, and aluminium mining alone generates 77 million tons of tailings worldwide every year.

Modern farming also requires more than just sunshine and rain. In the UK, farmers add an average of 100 kilograms of nitrogen fertiliser to every hectare of arable land and grassland each year. Whatever the crops don't absorb gets washed into the groundwater and ends up in our rivers, going from land to water pollution.

The low-tech solutions to land pollution are the three Rs – reduce, reuse, recycle – and these are in decreasing order of effectiveness. Reducing the amount of cardboard or cabbage you need to buy in the first place has a much bigger impact than simply recycling all the leftovers, because it also saves the energy that would have been required to process and transport them to you, and then collect and recycle them again afterwards.

But there are high-tech pollution solutions as well. Bioremediation uses selected strains of naturally occurring organisms to break down contaminants in the soil. Wood fungi,



Inside a single-stream recycling plant

The machine that separates your recyclables so you don't have to

1 Tipping floor
A steady stream of recycling collection vehicles arrives at the facility, dumping their cargo of mixed recyclables out onto the tipping floor. Drivers look out for any oversized objects like car engines that would cause damage to the plant machines.

2 Loading
Powerful loaders shunt piles of assorted recyclables into a large hopper, where they are tumbled over a rotating drum to loosen compacted materials. They then flow onto a giant conveyer belt, which whisks the jumble into the main facility.

3 Manual pre-sort
Teams of human sorters pick out non-recyclable items from the fast-moving stream, including crisp packets, plastic bags, shoes and nappies, as well as large items like scrap metal that might jam the machines.

4 Star screen sorting
A series of vibrating, rotating shafts, fitted with offset star-shaped discs, lift large and light materials like cardboard upwards; smaller items like paper, bottles and cans fall through and continue on the conveyer belt.

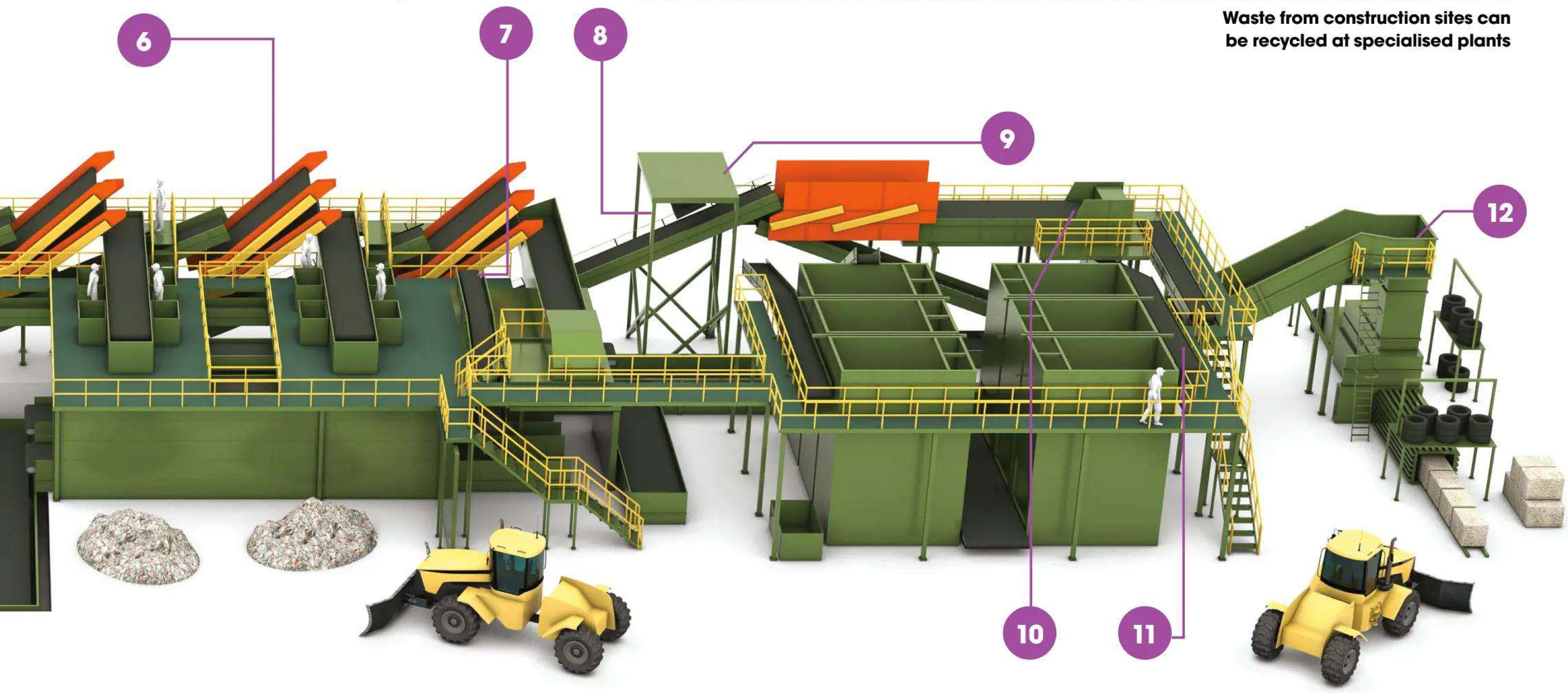
5 Manual sort
For a second time, teams of human sorters stand at intervals along the conveyer belt and look out for any smaller contaminants that might have snuck into the mix, such as personal electronics, trinkets, wallets and pieces of food.

6 Star screens round two
A trio of finer-grained star screens sift out different grades of paper, which are directed towards dedicated storage units. Glass, metals and plastics fall through the screens again and continue on the conveyer belt.

"UK farmers add an average of 100 kilograms of nitrogen fertiliser to every hectare of arable land each year"

for example, have been shown to break down the toxins in oil spills and also certain chlorine pesticides. Heavy metals like cadmium and lead can't be broken down, but certain plants will take them up through their roots and store them in their leaves or stems. This technique, which is known as phytoremediation, uses plants to soak pollutants from the ground so that they can be removed more easily. Chinese brake fern can even filter out arsenic in this way.

Waste from construction sites can be recycled at specialised plants



7 Glass sorter As they fall through the star screens, glass containers get crushed by the rotating stars. The fragments fall into bins below the screens, and are transported offsite to be sorted by colour and ground into coarse sand.

8 Steel magnet The remaining materials pass under a powerful rotating belt magnet, which lifts out tin and steel cans and drops them into a storage bunker. However, this usually only removes around four per cent of the recyclables passing through the plant.

9 Eddy current separator Since aluminium isn't magnetic, it is picked out using a strong reverse magnet called an eddy current separator. This uses spinning magnets to induce a current in the cans, which makes them fly off the belt and into a bunker.

10 Optical sorting with IR lasers Computerised scanners use infrared lasers to identify certain plastics by their optical properties. Once identified, an item will be thrust into a specific bunker by a directional burst of air.

11 Manual sorting The remaining plastics are carefully sorted by teams of workers. They also perform a last check, picking out and redirecting any recyclable items that have been missed by the mechanical processes and remain on the line.

12 Baler One at a time, the bunkers are opened, pouring out plastic, cans, metals or paper. Baling machines compress these into cubic bales ready to be taken to reprocessing plants for recycling. Any leftover materials at this point go to a landfill site.

Beijing issued its first ever 'red alerts' for hazardous smog in December 2015

Air pollution

With the potential to cross international boundaries, air pollution is a truly global problem

Air pollution is the introduction of gases and particles into the atmosphere that have harmful effects on living creatures and the built environment. According to the World Health Organization, 7 million premature deaths are caused every year by people inhaling polluted air – that's one in eight deaths worldwide. Once released into the atmosphere, pollutants are impossible to contain and, depending on prevailing weather patterns, have the potential to affect people who are hundreds or even thousands of kilometres from the source.

Over the last half century, the nature of the problem has altered. In the developed world, smog-causing emissions of noxious smoke, sulphur dioxide and particulates associated with incomplete fuel combustion have been curbed by technologies like flue-gas desulphurisation systems, soot scrubbers and catalytic converters. Gases that deplete the stratospheric ozone layer most aggressively have been outlawed and replaced by safer compounds, and today it's the threat of global warming that looms largest.

There is growing evidence, however, that respiratory problems like asthma might actually be caused by air pollution, not just triggered by it. Some researchers have even made tentative links between neighbourhood air quality and rates of childhood autism.

As with other forms of pollution, the best way to protect the environment is to avoid releasing these toxic elements in the first place. Conserving electricity, driving mindfully, and choosing to walk, cycle or take public transport are easy choices we can all make in order to breathe a little easier.

Atmospheric pollutants

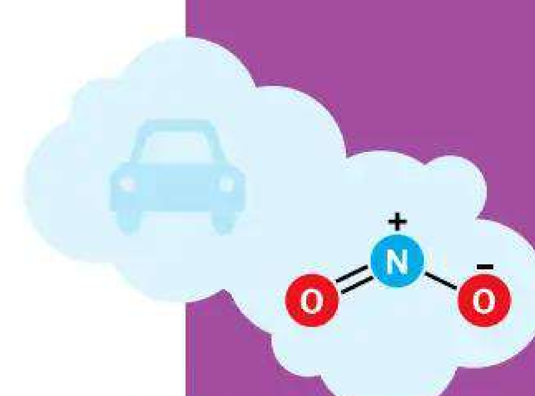
The major contributors to environmental damage

Carbon monoxide (CO)

This gas is produced when fossil fuels burn incompletely, with road vehicles being the predominant source.

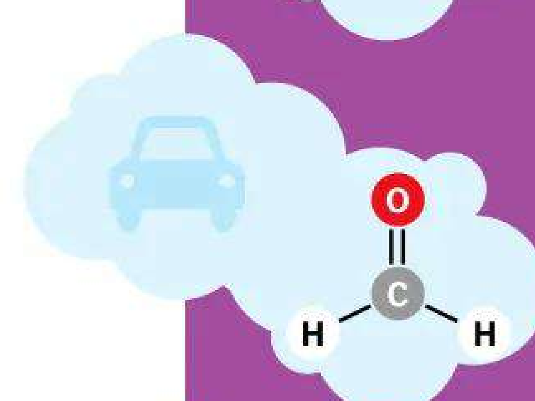
Ozone (O3)

This is formed when other pollutants react in the presence of heat and sunlight. It triggers lung irritation and asthma attacks.



Nitrogen oxides (NOx)

These form during fossil fuel combustion and contribute to global warming, smog and ground level ozone formation.

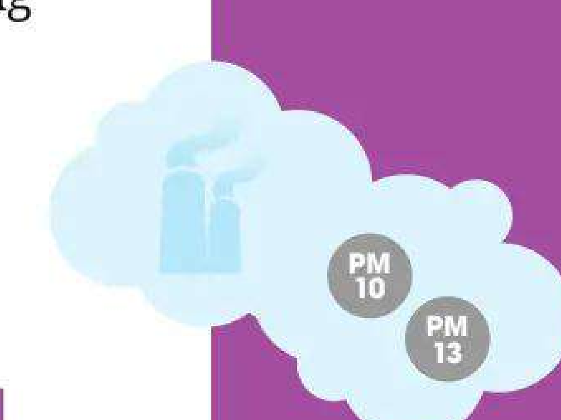


Volatile organic compounds (VOCs)

In the presence of pollutants, these carbon-based chemicals contribute to the formation of ground level ozone and smog.

Sulphur dioxide (SO2)

This is produced during incomplete combustion in coal-fired power stations and fireplaces. It contributes to smog and acid rain.



Particulates

These include airborne dust, dirt, soot and smoke. They can cause respiratory problems and environmental damage, such as acidification of lakes.

Ocean pollution

From oil and debris to sewage and toxic chemicals – our seas have it all

Oceans cover 71 per cent of our planet's surface and contain an estimated 1.5 million species, but that hasn't stopped humanity treating the sea as a giant rubbish bin. We're familiar with tragic images of seabirds whose feathers are clogged with viscous black oil, but tanker spills account for just a fraction of oil pollution in the sea; street runoff, vehicle exhausts and industrial waste are all chronic contributors to the problem.

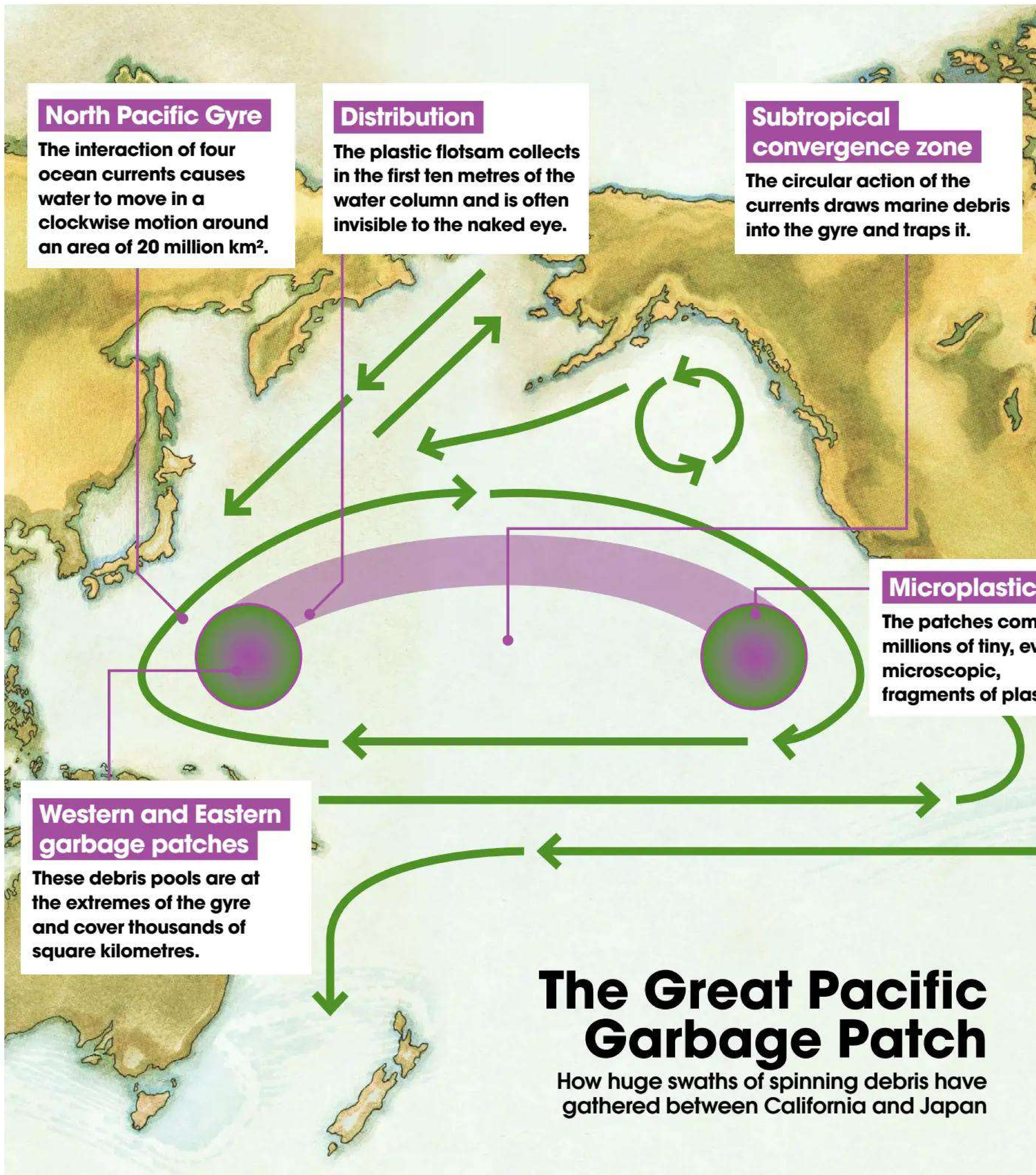
Indeed, almost all marine pollution stems from activities on land. Runoff from farms introduces pesticides and insecticides into the aquatic food chain, as well as an overabundance of nutrients in the form of fertiliser. This causes populations of algae to spike, draining the surrounding waters of oxygen and suffocating other marine life. Human-made rubbish is ubiquitous throughout the oceans, where it is corralled by currents into vast swirling 'garbage patches'. Many items, including fishing gear, glass, metal, paper, cloth and rubber, can take decades or even centuries to decompose.

The worst offenders – plastics – essentially persist forever, but are broken down under the Sun's UV rays into ever smaller pieces. The eventual soup of 'microplastics' – invisible to the naked eye – poses a threat to wildlife that ingests it, and to the entire food chain due to the leaching of harmful chemicals.

There are no easy solutions, but a burst of new technologies may begin to turn the tide. In just 18 months, 'Mr Trash Wheel', a filtering water wheel with its own Twitter account, has removed over 400 tons of rubbish from Inner Harbor in Baltimore, US. Proposals for open ocean filtration systems include a solar-powered 'vacuum boat' called SeaVax, that its inventors claim will suck up 22,000 tons of garbage each year.

The most common items washed up on beaches include plastic bottles and cutlery, and coffee cup lids. The good news is that means we can help by making simple changes to our lifestyles, like carrying reusable water bottles and utensils.

"Almost all marine pollution stems from activities on land"



Marine debris timeline

How long does common rubbish persist in the ocean?

Cigarette butt
The most common item found on beach clean-ups, cigarette butts make up 25 per cent of all collected debris. They contain a synthetic fibre that takes years to break down.

Aluminium can
An aluminium oxide coating makes aluminium cans very resistant to dissolving in sea water. Frustratingly, they are also one of the simplest items to recycle.

Plastic drink bottle
Plastics degrade into tiny pieces, but they never fully disappear. Americans alone throw away over 35 billion plastic water bottles per year.

Disposable nappy
Nappies are made from multiple layers, including various long-lived plastics like polythene and polyester. They easily outlive the child that wears them.

Tiniest life on Earth

Lifting the lid on the strange and wonderful creatures that inhabit a world usually out of sight

Life on Earth is divided into three domains – archaea, bacteria and eukaryotes – and all three contain examples of microscopic life. There is also some debate as to whether a fourth domain of life should be added to encompass biological entities such as viruses. Bacteria are prokaryotes and do not have a membrane-bound nucleus; instead, their genetic information is free in the cytoplasm. On average, they measure just a few thousandths of a millimetre in length, representing the smallest accepted life forms known to science.

Archaea are similar in structure to bacteria and were originally thought to belong to the same domain, but they have distinct genetic differences. Archaea tend to inhabit some of the most extreme environments on the planet, and can be found in salt lakes, underground petroleum reserves and even some deep-sea thermal vents.

Eukaryotes include animals, plants, fungi and protists. Eukaryotic cells have membrane-bound organelles; their genetic information is enclosed in a nucleus, energy is produced inside the folded membranes of mitochondria and proteins are produced and packaged inside membrane stacks. This extra layer of organisation enabled the evolution of the enormous variety of single and multicellular micro-organisms that belong to this domain from humans to ants.

There are many advantages to being small. Exchange of gases and nutrients can be done by diffusion, eliminating the requirement for complicated circulatory and respiratory systems, while incoming chemical or tactile signals only have to be transmitted for short distances. A simple structure also allows for rapid replication, shortening generation times and allowing more mutations to build up over a given period, granting rapid adaptation to environmental changes.

An organism can only be so small if it is going to be able to survive on its own though. Free-living organisms must be able to transform energy from their environments – to make their own biological molecules and to

This head louse is a parasite, unable to survive on its own

What is life?

The definition of life is debated, but most scientists agree on some fundamental conditions – one of the most important of which is the ability of an organism to make copies of itself. Living things are also able to transform energy from their environment, using it to maintain structural organisation, primarily for growth and reproduction.

A virus particle (or virion) does not meet the classical defining criteria for life. It is essentially a vehicle for the transfer of genetic information – DNA or RNA packaged into a protective coat – and cannot metabolise, grow or reproduce on its own. However, when viruses hijack the biological machinery of a cell, they direct it to replicate the viral genome in order to produce viral proteins and to organise the components into new virions. Viruses evolve in response to environmental pressure, so could be considered to be extremely simplified parasites, raising the debate as to whether they do actually deserve to be classified as a form of life.

1 million spherical cocci bacteria could fit on this square

assemble and organise them for growth and replication. This requires a complex arsenal of internal cellular machinery, including nucleic acids to store genetic information, equipment to translate that genetic message into proteins and sufficient solvent to allow metabolic reactions to take place. One of the smallest known free-living organisms is an archaea known as ARMAN, which measures a minuscule 200 nanometres long. It has an extremely sparse genome, containing the bare minimum required to survive without resorting to parasitism.

Many of the world's smallest free-living organisms are aquatic. Living suspended in water provides a ready supply of dissolved gases and nutrients. Some float freely, while others have developed strategies to anchor themselves in one place, adhering to the surface of rocks or the mucous membrane of an animal's gut, ensuring they won't stray too far from their environmental niche.

Many other micro-organisms rely on parasitism for survival. Exploiting a host allows parasitic life to lose the genes responsible for some biological functions, saving energy and space and allowing them to reproduce more rapidly in response to any defence mechanisms that may evolve in their host.

In order to study these lifeforms, scientists use a range of techniques. The 'larger' organisms (measuring between 0.2 micrometres and one millimetre) can be imaged under an optical microscope, and fluorescent stains are often used to label different biological components. To study the structure of smaller organisms, or to study larger organisms in more detail, electron microscopes are called upon – the most powerful of which can resolve a single atom.

Imaging is accompanied by a vast array of biochemical techniques to analyse cellular processes from metabolism to signalling pathways. Gene sequencing and genetic manipulation are often used to study the function of different genes. Not only does this provide valuable information about the biology of micro-organisms, but manipulation of their genetic information also has enormous potential for medical treatment.

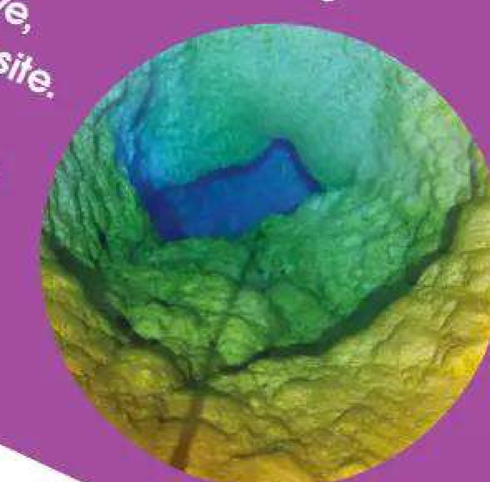
NANOMETRES

Porcine circovirus
Type: Virus
Size: 17nm
Info: This simple virus in pigs achieves its tiny size by hijacking the cellular machinery of its host. It carries genetic information for just three proteins: two to replicate its genetic material and one to make up the capsule that surrounds each virus particle. The rest of the work is done by the host's own proteins.

Nanobes
Type: N/A
Size: 20-30nm
Info: Nanobes are tiny, filament-like structures, brought to scientific attention by their presence in a Martian meteorite. It is hypothesised that these structures represent the smallest form of life, but the evidence is not conclusive and whether the biological molecules required to sustain life could fit inside a nanobe is currently unknown.

Mycoplasma genitalium
Type: Bacteria
Size: 200-300nm
Info: This bacterium represents cellular life at its simplest. It has one of the smallest genomes of any cell, containing just 582,970 base pairs (the human genome has over 3 billion), divided into 521 genes. There are smaller bacteria, but they lack the genes required to support themselves and must live as parasites in association with other species.

Nanoarchaeum equitans
Type: Archaea
Size: 400nm
Info: Nanoarchaeum equitans has the smallest genome of any living organism (a definition that excludes viruses). It cannot make many of the biological molecules that it requires to survive, so lives as a parasite. As a heat-loving extremophile, it can be found in and around hydrothermal vents and hot springs.



Bacteria under attack
Disease-causing bacteria have problems of their own: bacteria-infecting viruses

Attachment
Bacteriophages attach to molecules on the surface of their target before injecting their genetic material into the cell.

Replication
The virus hijacks the molecular machinery of the bacterium, using it to make copies of viral DNA and produce viral proteins.

Assembly
DNA is packaged into a protein capsule at the head of the virus and the tail proteins assemble at the base.

Release
Some bacteriophages use enzymes to burst the host membrane. Others force the bacterium to release new viruses.

All shapes and sizes
Under the microscope, the dazzling array of bacterial types becomes clear

Diplococci
Spherical bacteria often form aggregations and diplococci like Neisseria will stick together in pairs.

Staphylococci
Other spherical bacteria cluster in bunches resembling berries. Most are harmless, but this group contains the superbug MRSA.

Streptococcus
Cocci can create long strings by dividing along only one axis, producing daughter cells in line with the chain.

Pseudomonas
These rod-shaped bacteria have one or more flagella, which they use like a propeller for forward motion.

Mycobacterium tuberculosis
The destructive causative agent of tuberculosis is rod-shaped and can come together to form chains.

Spirillum
There are only two known species of spiral-shaped bacteria. Spirillum have a twisted, elongated structure.

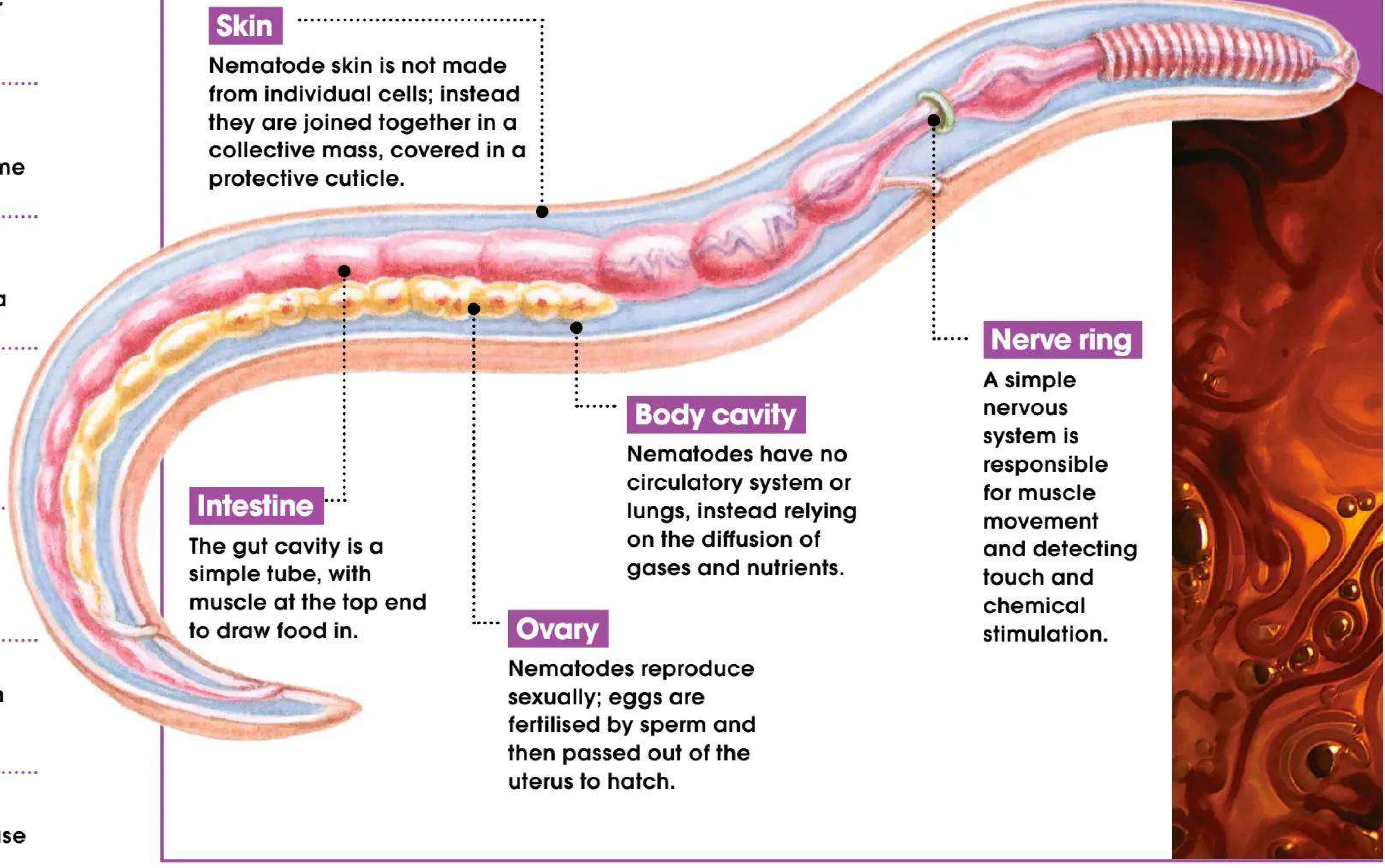
Salmonella enterica
This rod-shaped bacterium is covered in protrusions called fimbriae, allowing it to stick to surfaces, like the inside of an animal's intestine.

Treponema pallidum
These elongated bacteria use a corkscrew-like motion to move through fluids, twisting into a helical shape.

Vibrio
Bacteria in this genus are a variation on the rod shape, with a curved, tapered end, somewhat resembling a comma.

Clostridium tetani
The bacterium responsible for the disease tetanus is shaped like a tennis racquet.

Anatomy of a nematode
Take a look inside one of the simplest multicellular organisms on Earth



Skin
Nematode skin is not made from individual cells; instead they are joined together in a collective mass, covered in a protective cuticle.

Intestine
The gut cavity is a simple tube, with muscle at the top end to draw food in.

Body cavity
Nematodes have no circulatory system or lungs, instead relying on the diffusion of gases and nutrients.

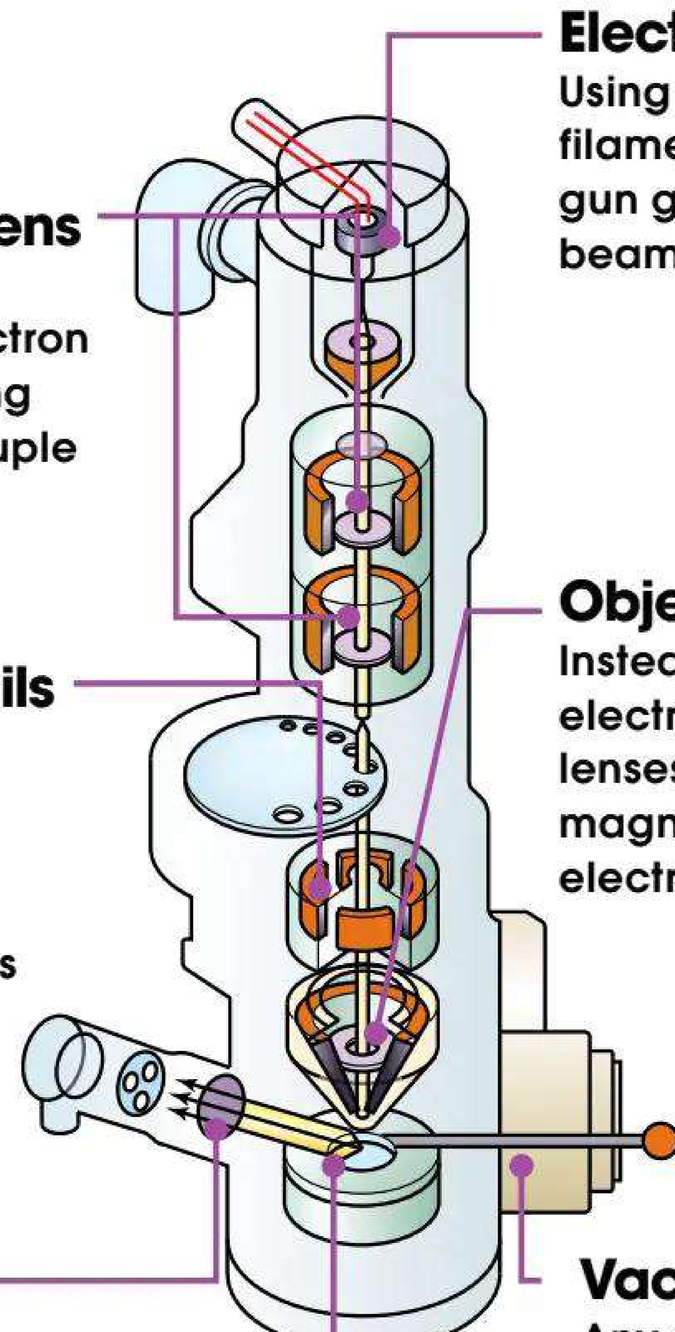
Ovary
Nematodes reproduce sexually; eggs are fertilised by sperm and then passed out of the uterus to hatch.

Nerve ring
A simple nervous system is responsible for muscle movement and detecting touch and chemical stimulation.

A low temperature scanning electron microscope is used to view anatomical structures needed to identify nematodes

Inside an SEM

Scanning electron microscopes can magnify samples to 300,000 times their size, but what tech powers them?



Electron gun
Using a tungsten filament, an electron gun generates a beam of electrons.

Condenser lens
A condenser focuses the electron beam, producing a spot just a couple of nanometres in diameter.

Objective lens
Instead of glass, electron microscope lenses are made from magnets that bend the electron beam.

Scanning coils
Scanning coils deflect the electron beam, moving it in a rectangle across the surface of the sample.

Detector
Scattered and emitted electrons and EM radiation are measured and used to construct an image of the sample.

Vacuum chamber
Any air would disrupt the electron beam, so samples are tested in a vacuum.

Sample
Samples are fixed to preserve their structure, dried and then coated with gold before they are imaged.

Ostreococcus

Type: Plant

Size: 800nm

Info: These algae are the smallest free-living eukaryotes on the planet. Unlike bacteria and archaea, some of the machinery found inside eukaryotic cells is enclosed in membrane-bound structures called organelles. Additionally, their DNA is not free in the cytoplasm, like it is in bacteria, but instead enclosed in a nucleus, like human DNA. These cells are so small that they contain just one mitochondrion to generate energy and one chloroplast for photosynthesis, compared to tens or even hundreds in other plant cells.

MICROMETRES

Nematode

Type: Roundworm

Size: 80 micrometres

Info: Nematodes, or roundworms, are some of the smallest multicellular organisms; for context, Caenorhabditis elegans has less than 1,000 cells and just 300 neurons. This laboratory nematode was the first multicellular organism to have its genome sequenced and its simple body plan is used as a model to study development.

Stygotantulus stocki

Type: Crustacean

Size: 94 micrometres

Info: At less than 0.1mm (0.004in) long, these tiny creatures are the smallest known arthropods. They have evolved as parasites, relying on larger crustaceans like copepods to survive. The copepods themselves measure just 1-2mm (0.04-0.08in) in length, but are able to get by on their own.

Top 5 uses of microbes today

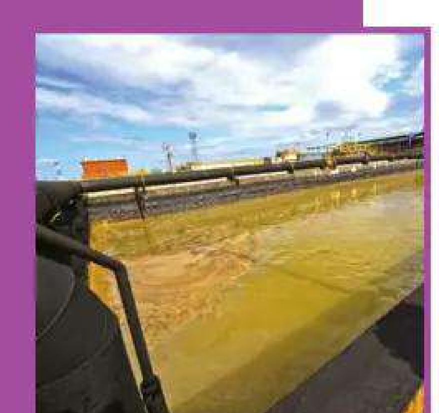
1 Dairy goods

Milk contains the sugar lactose, which can be broken down by bacteria to form lactic acid. It's this lactic acid that gives yoghurt, cheese and other popular fermented dairy products their signature sour taste.

2 Antibiotics

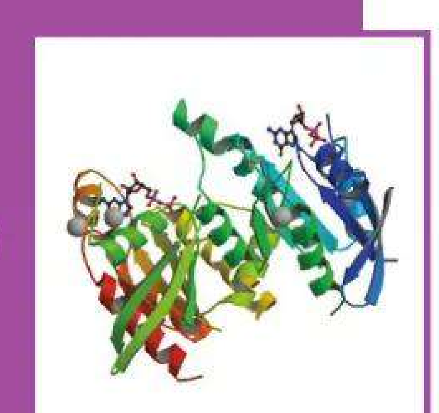
Certain moulds, like penicillium, produce natural antibiotics that can incapacitate bacteria. By altering the structure of these chemicals, we have created powerful and effective drugs to fight infection.

3 Sewage busters



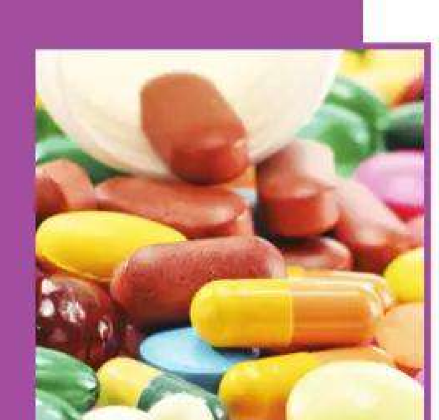
Micro-organisms are used at several stages in the treatment of sewage. They are effective in removing nitrogen, phosphorus and other biological contamination from the waste, cleaning it.

4 Making protein



Bacteria readily take up and absorb DNA, which allows scientists to use them as miniature factories of sorts. They utilise that function to produce proteins using genes from other species.

5 Vitamins



Us humans, just like plants and animals, cannot produce the essential vitamin B12 on our own. Instead we rely on various archaea and bacteria to do the work for us.

Eriophyid mites

Type: Arachnid

Size: 125 micrometres

Info: These parasitic arachnids have just two functional pairs of legs, look like worms and travel from plant to plant on the wind. Infestation causes the plants to form nutrient-rich growths known as galls (below), which the mites use as a food source and protection from predators.

Dicopomorpha echmepterygis

Type: Insect (wasp)

Size: 140 micrometres

Info: The males of this wasp species are the smallest insects known. They are blind, have no wings and like many other tiny organisms, they lead a parasitic lifestyle, this time inside the eggs of other bugs. The females are much larger and are able to fly.

Nanosellini

Type: Insect (beetle)

Size: 300 micrometres

Info: The 27 species of Nanosellini beetle each measure less than a millimetre in length, with some just 0.3mm (0.01in) long. They are the smallest of the beetles and feed on fungal spores, generally living on top of, or inside, the fungus itself.

Mellisuga helenae

Type: Bird

Size: 50mm

Info: The bee hummingbird is about the same size as a large insect and is the smallest living bird, laying eggs barely larger than a pea. Like its namesake, it is a pollinator, feeding on nectar and in the process becoming covered in pollen, which it then transports to a different flower.

MILLIMETRES

Parvulastra parvivipara

Type: Starfish

Size: 5mm

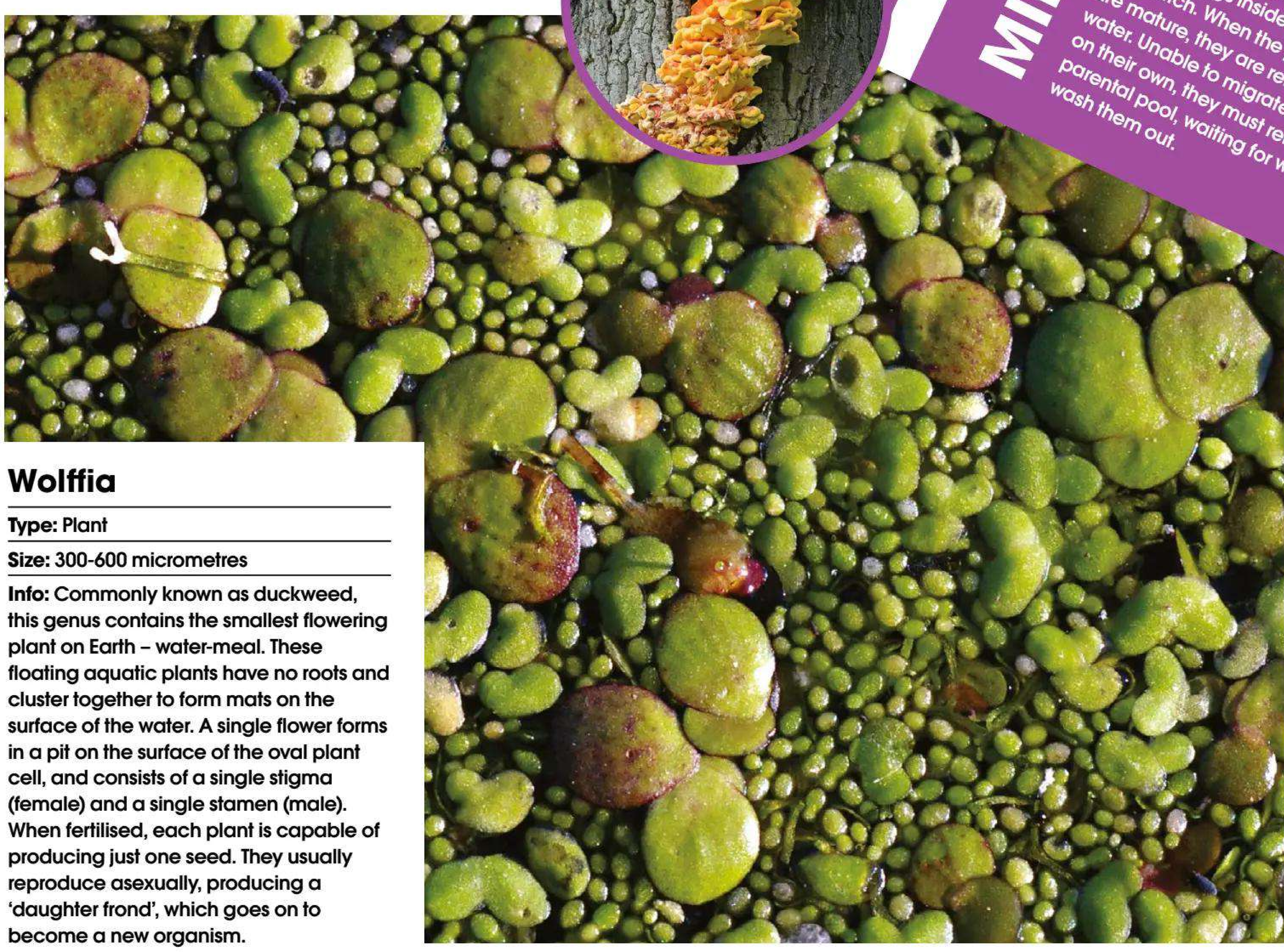
Info: This yellow-orange starfish is found in rock pools and on granite rocks in southern Australia and measures less than a centimetre (0.4 inches) across. This invertebrate gives birth to live young, incubating its fertilised eggs inside its body until they hatch. When the juvenile starfish are mature, they are released into the water. Unable to migrate to new pools on their own, they must remain in their parental pool, waiting for waves to wash them out.

Echinocyamus scaber

Type: Sea urchin

Size: 6mm

Info: Sea urchins have a spiny outer shell, live in oceans worldwide and can be found on the seafloor down to 5,000 metres (16,400 feet). The smallest species is just six millimetres (0.2 inches) across – about the size of a Tic-Tac.



Wolffia

Type: Plant

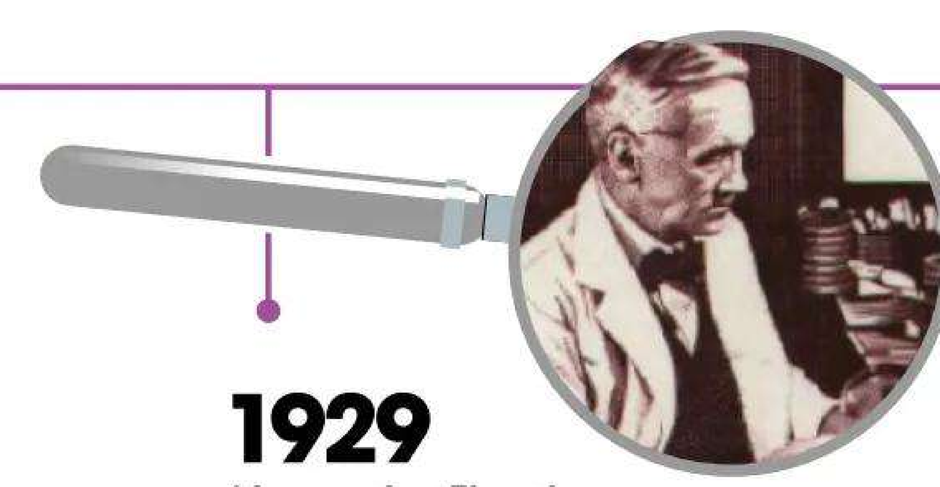
Size: 300-600 micrometres

Info: Commonly known as duckweed, this genus contains the smallest flowering plant on Earth – water-meal. These floating aquatic plants have no roots and cluster together to form mats on the surface of the water. A single flower forms in a pit on the surface of the oval plant cell, and consists of a single stigma (female) and a single stamen (male). When fertilised, each plant is capable of producing just one seed. They usually reproduce asexually, producing a 'daughter frond', which goes on to become a new organism.

"Being small and evolving quickly has enabled micro-organisms to adapt to life in the most inhospitable of places"

Shrinking science

We take you through the major breakthroughs in discovering the tiniest lifeforms on Earth



1890
Robert Koch publishes four criteria showing bacteria as causative agents of disease.

1893
Ticks are found to carry a parasite causing disease in both animals and humans – the first example of a zoonotic infection.

1911
Francis Peyton Rous discovers cancer can be caused by viral infection. He later receives a Nobel prize.

1929
Alexander Fleming publishes his work on penicillin, demonstrating its ability to kill gram-positive bacteria.

Surviving extremes

Extremophiles are a group of organisms specialised for survival in Earth's most challenging environments. These resilient organisms can be seen in all three domains of life, but the majority are archaea and bacteria.

Acidophiles and alkaliphiles live in extremes of pH, piezophiles at extreme pressures and thermophiles at temperatures exceeding the boiling point of water. Being small and simple, reproducing rapidly and evolving quickly has enabled micro-organisms to adapt to life in the most inhospitable of places, from the Atacama Desert to hundreds of metres below the Antarctic ice.

Complex multicellular animals can also survive in harsh conditions. The tardigrade, or water bear, can dehydrate its cells, preventing the formation of destructive ice crystals. It can withstand extreme temperature, intense pressure, high doses of radiation and even survive ten days in the vacuum of space!

The tiny Brookesia micra chameleon can be found on Madagascar – if you look very closely!

Photocorynus spiniceps

Type: Fish

Size: 6.2-7.3mm

Info: Male anglerfish of the Photocorynus spiniceps species are the smallest known adult fish. Their primary function is to pass on their genetic information and they spend most of their lives attached to the larger female, which use bioluminescence to lure in their prey and have to keep their male passengers alive.

Paedophryne amauensis

Type: Frog

Size: 7-8mm

Info: The world's smallest known vertebrate is Paedophryne amauensis, native to Papua New Guinea. These fingernail-sized frogs hide on the forest floor, feeding on small insects. Their eggs do not hatch into tadpoles, and instead, fully formed 'hoppers' emerge, increasing in size until they reach adulthood. The frogs make insect-like noises and can jump distances 30 times their body length – an impressive 20 centimetres (7.9 inches).

Thorius arboreus

Type: Salamander

Size: 17mm

Info: Thorius arboreus is currently the smallest known salamander and lives in Mexico. There are several species of miniature salamander and more are still being discovered all the time, so – like with all tiny organisms – it is possible that an even smaller species exists but has yet to be found.

Craseonycteris thonglongyai

Type: Bat

Size: 30-40mm

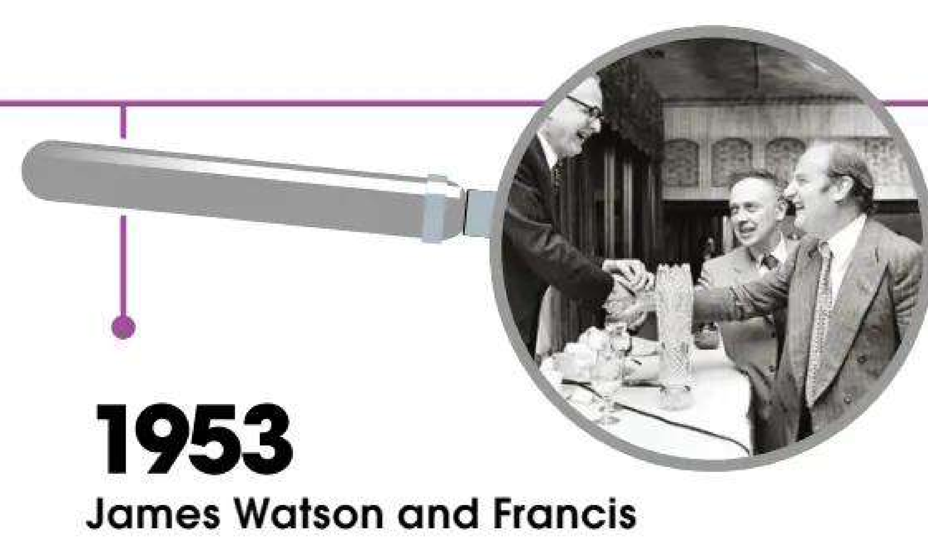
Info: Kitti's hog-nosed bat, also known as the bumblebee bat, is a contender for the title of world's smallest mammal, measuring just 30 millimetres (1.2 inches) long and weighing less than two grams (0.07 ounces). It is found only in Thailand and Burma, living in limestone caves. The Etruscan shrew weighs even less, at just 1.8 grams (0.06 ounces), but its tail makes it slightly longer.

Brookesia micra

Type: Chameleon

Size: 15-19mm

Info: This tiny lizard from Madagascar is one of the world's smallest reptiles. Their size is the result of 'island dwarfism'. Animals isolated on an island must compete for limited resources; smaller organisms take up less space and require less food, enabling them to survive when the island becomes overpopulated and resources become scarce. Brookesia micra have only been found in a single square kilometre on the island.



1949
Lab techniques to grow poliovirus inside human cells allow viruses to be studied outside the body.

1953
James Watson and Francis Crick publish the double helix structure of DNA, paving the way for genetic analysis of micro-organisms.

1979
Smallpox is eradicated following the last natural case of infection in Somalia.

1983
HIV is identified as the causative agent responsible for acquired immunodeficiency syndrome (AIDS) in humans.

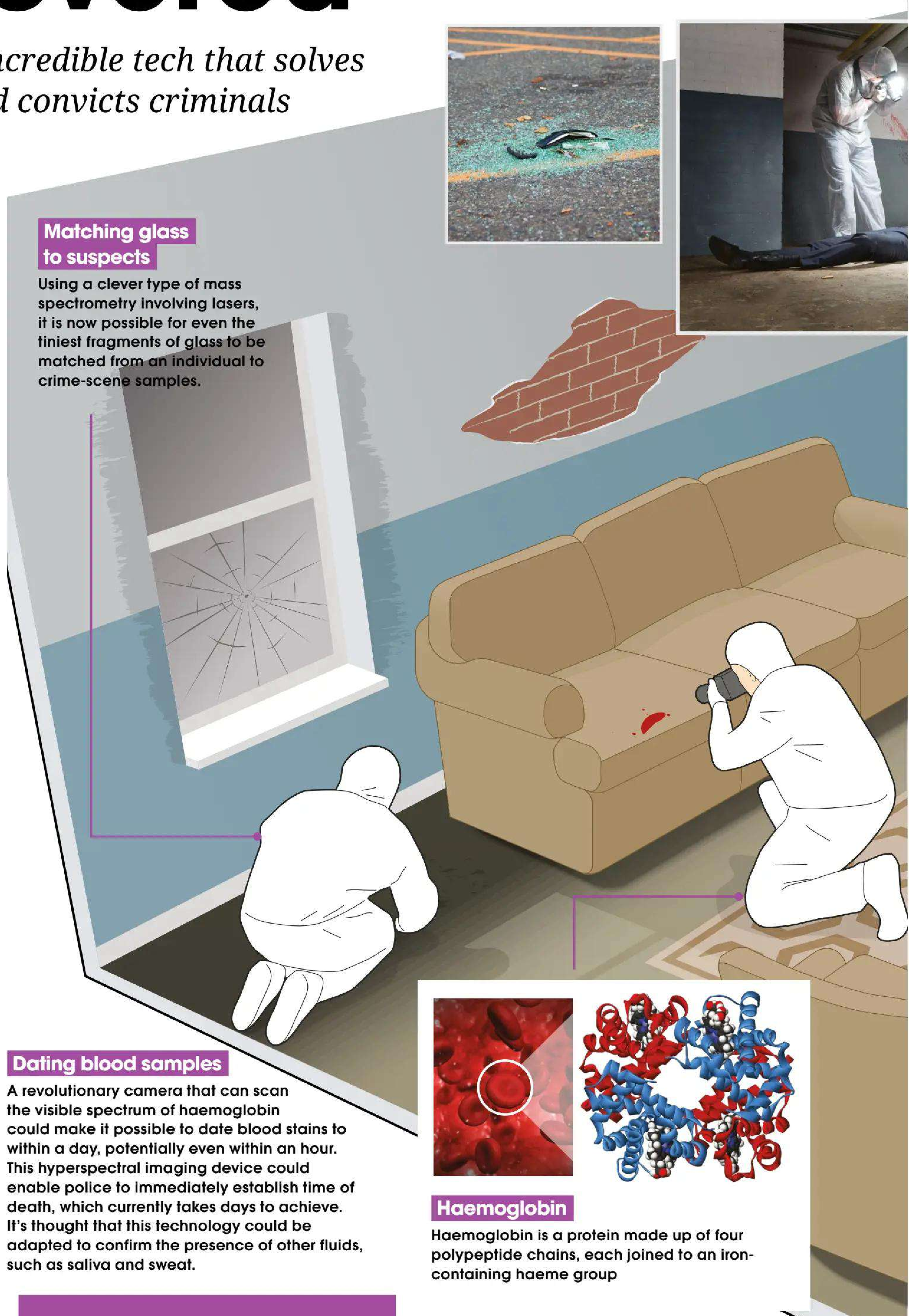
Forensic science uncovered

Revealed: the incredible tech that solves crimes and convicts criminals

Forensic science has never been under more scrutiny than right now. The huge popularity of TV shows relating to forensics has not helped. The general public's expectations have been raised; they expect 100 per cent accuracy and rapid results, both of which are misrepresented in many crime dramas. In some instances, this has led to miscarriages of justice, through the wrongful representation of various theories as undisputed fact. The public struggles to appreciate this; forensic science has long been thought of as a tool to expose wrongful convictions, rather than cause them. The popularity of forensics in entertainment has also aided criminals; they now have greater awareness of many of the techniques used by forensic scientists, enabling them to avoid detection with greater success.

However, the technology used in forensics has developed hugely in the last century. Toxicologists no longer have to taste stomach contents to check for poisons, which was an unsavoury part of their job description during Victorian times. Instead, they can now use precise analytical techniques, such as mass spectrometry and high-performance liquid chromatography, to determine the exact quantity of compounds present in any test sample. DNA technology has breathed life into cases that have been left untouched for decades, and continues to be refined for greater accuracy.

Forensic technology has improved the police's ability to solve crime, but improvements are still needed. Experts are constantly trying to reduce the length of time analysis takes. The amount of evidence that needs analysing has created a huge backlog, which means evidence has to be prioritised by what is most likely to reveal probative evidence. It will be fascinating to see how forensic technology develops over the coming years and whether new techniques we've featured speed up investigations and lead to convictions.



Matching glass to suspects

Using a clever type of mass spectrometry involving lasers, it is now possible for even the tiniest fragments of glass to be matched from an individual to crime-scene samples.

Dating blood samples

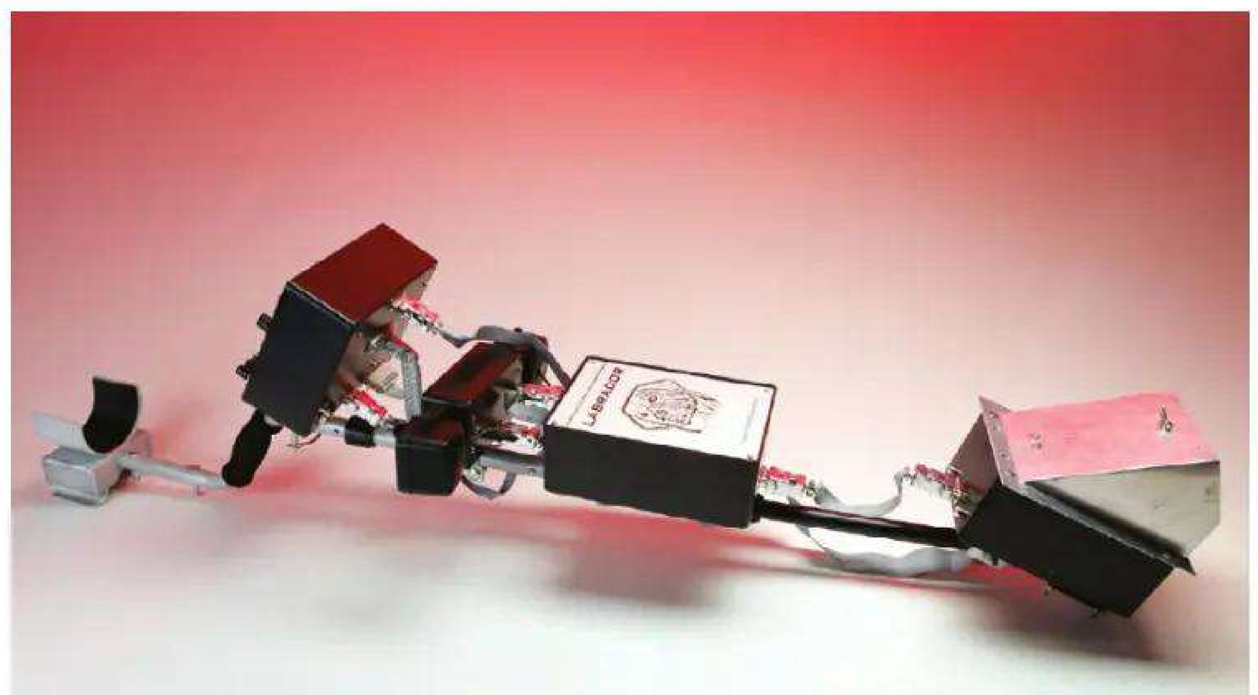
A revolutionary camera that can scan the visible spectrum of haemoglobin could make it possible to date blood stains to within a day, potentially even within an hour. This hyperspectral imaging device could enable police to immediately establish time of death, which currently takes days to achieve. It's thought that this technology could be adapted to confirm the presence of other fluids, such as saliva and sweat.

Haemoglobin

Haemoglobin is a protein made up of four polypeptide chains, each joined to an iron-containing haeme group

Sniffing out hidden graves

Locating hidden graves is both timely and costly, impacting law enforcement and military operations globally. The lightweight analyser for buried remains and decomposition odour recognition device – LABRADOR for short – claims to help find hidden graves. As our bodies decay, over 400 chemicals are released, producing a unique chemical signature that this device identifies. Its potential applications are vast, and include detecting narcotics, accelerants and even explosives.

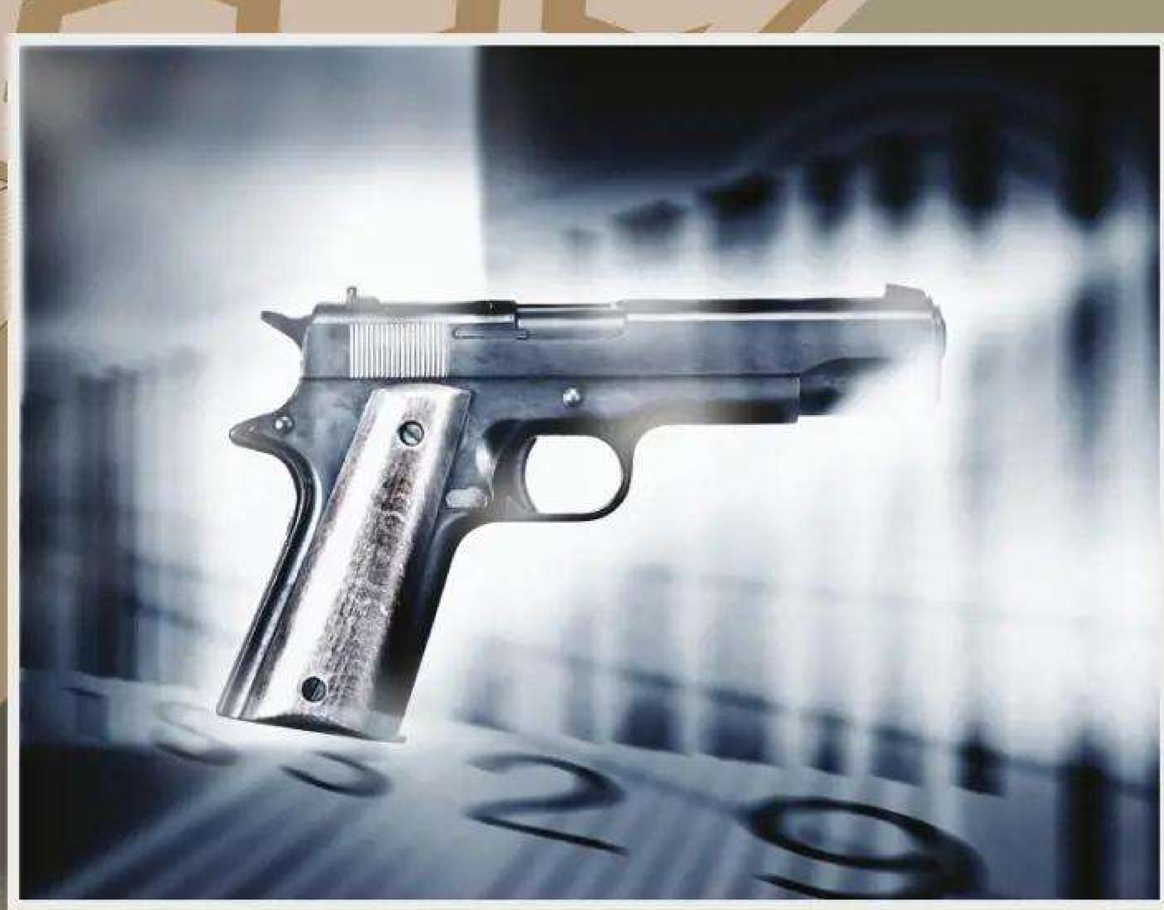


Crime-scene photography

When photographing a crime scene, it is imperative the photographer does not delete a single image, as this would be deemed as tampering with evidence.

Area of convergence

When bloodstain pattern analysts arrive at a crime scene, they will examine the distribution, size, shape and location of the bloodstains, to determine what has happened. Using the stringing method, the analyst will record the location of each spatter by employing the coordinate system. By determining both the angle and direction of each spatter, the starting point of the bloodshed and the victim's location are established.



Crystal pattern mapping

In order to make the identification of stolen goods harder, criminals will remove any form of serial number. By using electron backscatter diffraction (EBSD), it is possible to map the deformations in the metal's crystal structure, revealing the removed information. This technique could prove useful for reconstructing vehicle identification numbers, or even the imprints left on ammunition casings.

Blood pattern analysis

Cast-off

Cast-off stains are often formed when a bloodied weapon is swung through the air, casting blood onto a nearby surface.

Shadowing or ghosting

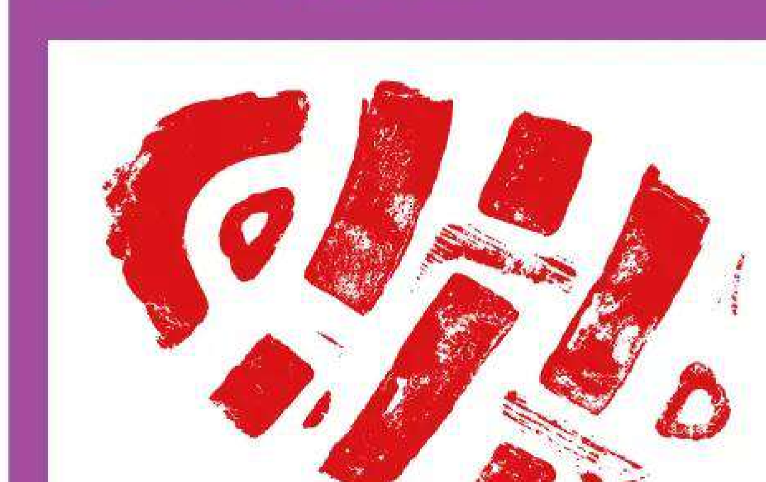
A gap in an otherwise consistent spatter typically indicates that an object was present at the time of the incident.

Swipes and wipes

Wipes are seen when blood on a surface is smeared, whereas swipes occur when an object covered in blood brushes a separate surface.

Expiratory blood

Blood exhaled by a person creates a unique pattern. This is typically misty, somewhat resembling high-velocity spatter.



Transfer

Transfer patterns form when a bloody object is pressed against a clean surface. This is often seen with bloody footprints.

Virtual autopsy

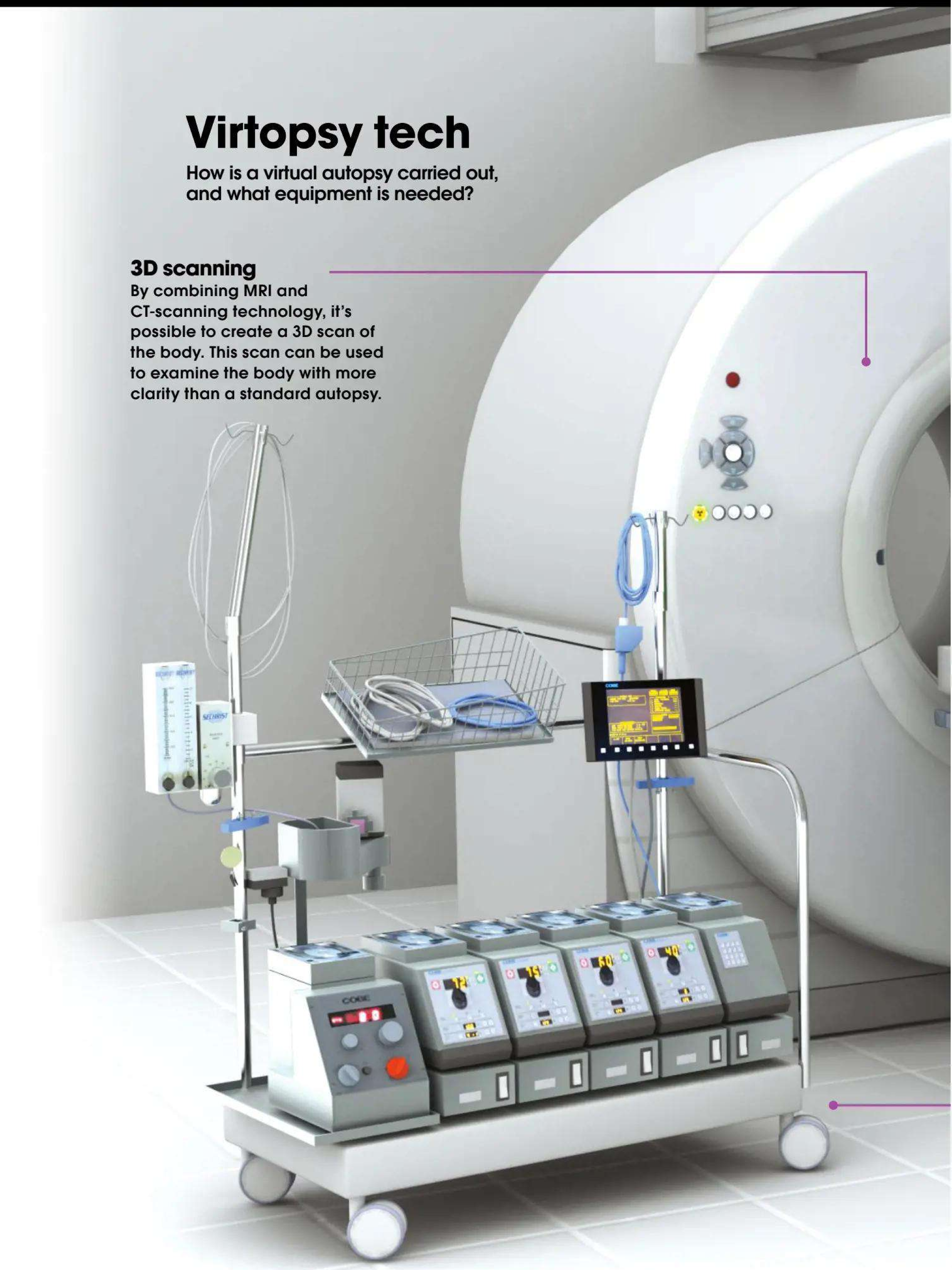
Can cause of death be established without dissecting a corpse?

Autopsies are a messy business in more ways than one. They can take hours to perform, and further analytical results can take months to produce. This not only delays forensic investigation; it can also add to the grief the deceased person's relatives experience. On top of this, researchers believe more than ten per cent of post-mortems are not completed to a satisfactory standard, meaning many suspicious deaths are never correctly identified.

The new virtual autopsy, or 'virtopsy', aims to speed up the entire process and achieve faster results. They offer the advantage of preserving a virtual form of the body, which can be continually reviewed and analysed. This will greatly increase accuracy, as multiple experts will be able to simultaneously examine the corpse, which is impossible to do during traditional post-mortems. The ability to gather nondestructive findings is a huge benefit of a 'virtopsy'; many families would rather their loved ones' bodies weren't subjected to the rigours of a traditional post-mortem. By using the virtopsy software, precise areas of interest can be chosen for further investigation, allowing pathologists to reduce the time they spend physically looking for clues in the body. Although unlikely to completely replace the traditional autopsy, the virtopsy has huge potential to speed up the process and greatly reduce the chance of missing vital evidence.

Virtopsy tech

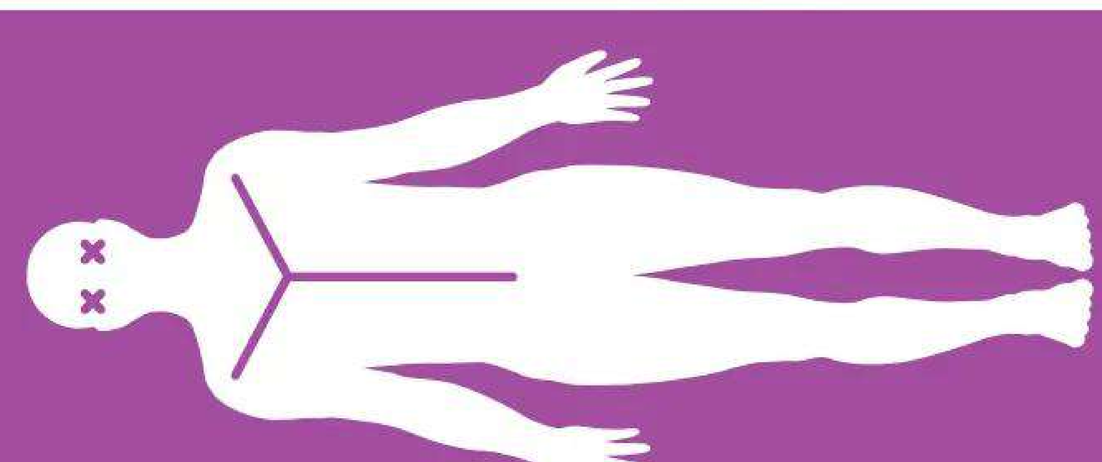
How is a virtual autopsy carried out, and what equipment is needed?



3D scanning

By combining MRI and CT-scanning technology, it's possible to create a 3D scan of the body. This scan can be used to examine the body with more clarity than a standard autopsy.

How traditional autopsies are performed



1 The Y-incision

The pathologist will perform a Y-shaped incision by cutting from each shoulder to the sternum, then down to the abdomen. This allows access to the major organs.

2 Organ removal

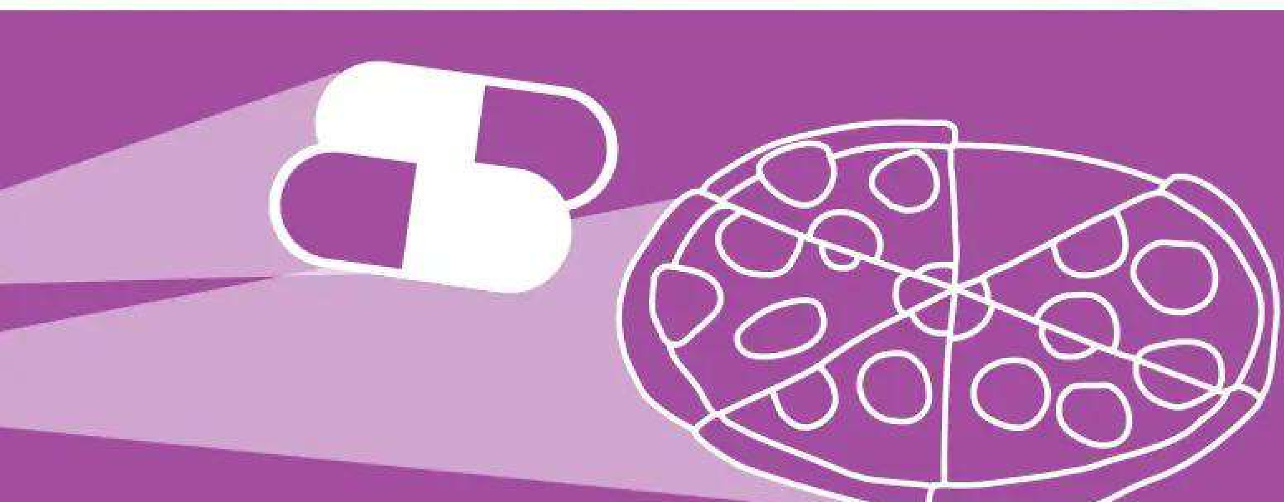
All of the body's major organs are removed and weighed for comparison. Blood and DNA samples are obtained and the heart is examined for signs of poisoning.

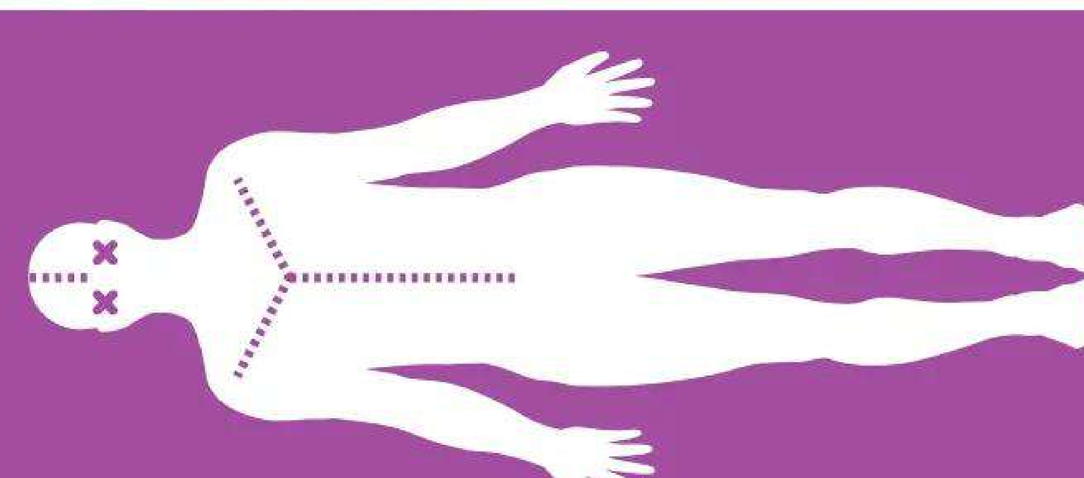
"Precise areas of interest can be chosen for further investigation"

High-resolution surface scanner
During an autopsy it's easy to miss a tiny fibre. This machine accurately scans the entire body, providing a detailed picture of what's on the skin's surface.

Heart-lung machine
During a virtual autopsy, this machine will circulate contrast solutions around the body, allowing clear visualisation of any circulatory problems that may have contributed to death.

Computer-supported biopsy
This machine works to choose the best tissue and fluid samples for analysis, which it can then help to analyse once they are collected.





3 Stomach contents
The stomach contents reveal the deceased's last meal. Time of death can also be calculated by analysing the amount of digestion that has taken place.

4 Brain examination
The brain is thoroughly examined for signs of injury or abnormality. Often it will be preserved in formalin, which will harden the brain, allowing it to be dissected with greater accuracy.

5 Replacement
After all of the previous procedures have been conducted, the organs will be placed back inside the body cavity and the Y-incision will be sewed up. Samples may be further analysed.

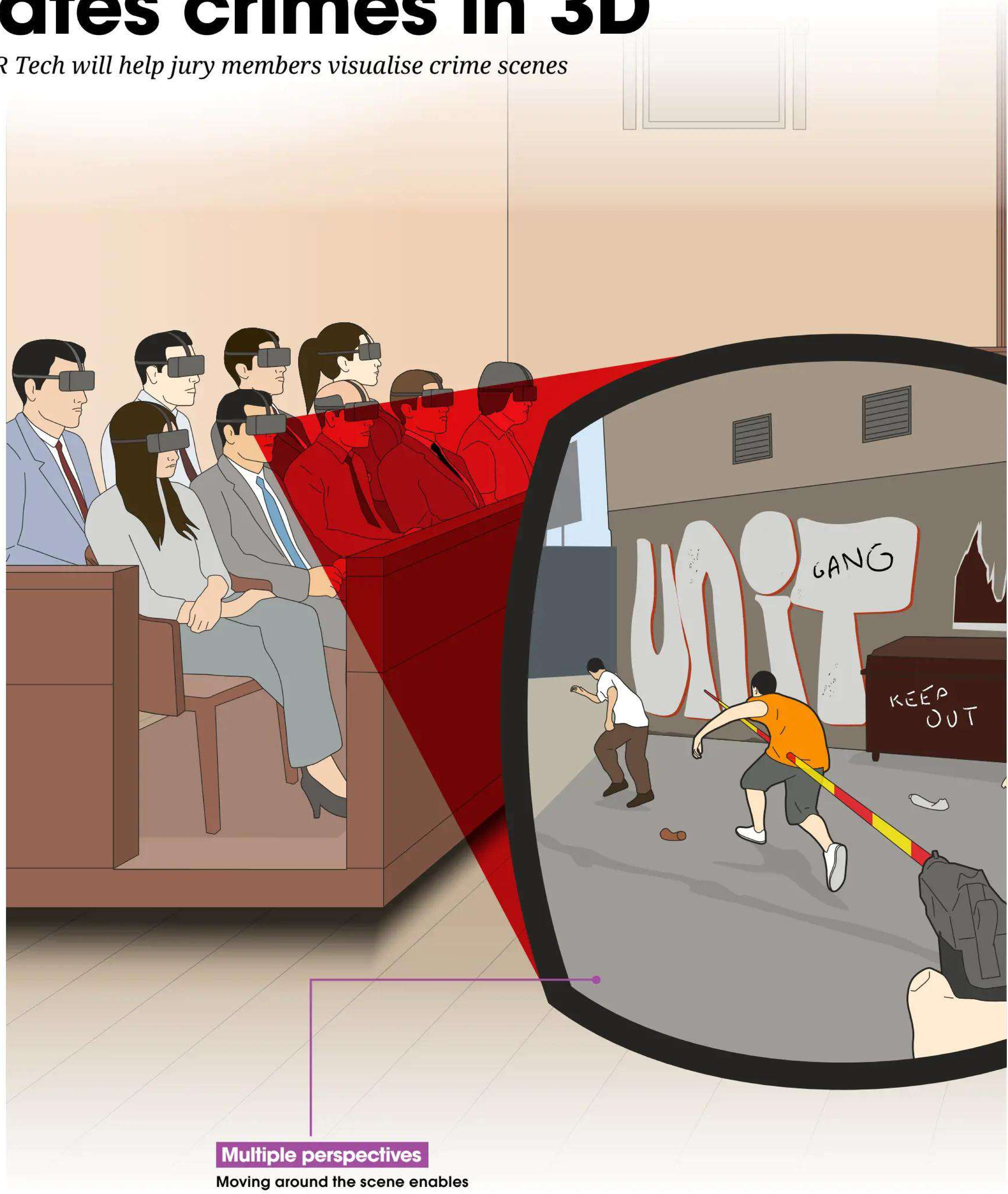
Forensic holodeck recreates crimes in 3D

New VR Tech will help jury members visualise crime scenes

Reconstructing a crime scene is one of the toughest jobs for any forensic scientist. This is particularly apparent when they give evidence in court. It's vital that both the judge and jury are able to develop detailed knowledge of any crime scene, in order to figure out what happened as well as the precise order of events. Without live footage of the scene, this has been incredibly difficult to achieve; photos of the scene and other types of evidence presented to the jury often leave much to the imagination.

By combining MRI, CT, laser-scanning technology, camera footage, eyewitness statements and the virtual reality headset, Oculus Rift, the forensic holodeck has been created. Using this new technology, all members of a courtroom may soon be able to walk through the crime scene in high-resolution 3D. Named after the simulated-reality device featured in *Star Trek*, an advantage of the forensic holodeck is that it can simplify a scene. This can help show exactly the evidence in question, or make particularly violent scenes less traumatic for the jury. Being able to appreciate a particular individual's line of sight is another significant benefit, as this can show whether someone is telling the truth about what they saw, or whether a suspect could be seen by certain individuals.

The Oculus Rift is able to measure the user's orientation in real time, which allows crime scenes to be viewed with the correct perspective. Originally designed for use in the world of videogames, the Oculus Rift has been modified so that it can measure the user's position with the help of an optical tracker.



Multiple perspectives
Moving around the scene enables the user to appreciate the different perspectives of the people involved, which may help to explain why their accounts of the events differ.

At the scene of the crime

VR tech puts the jury right inside the crime scene

Bullet trajectories

The red and yellow line shows clearly the bullet's trajectory, revealing how close certain people were to being shot.

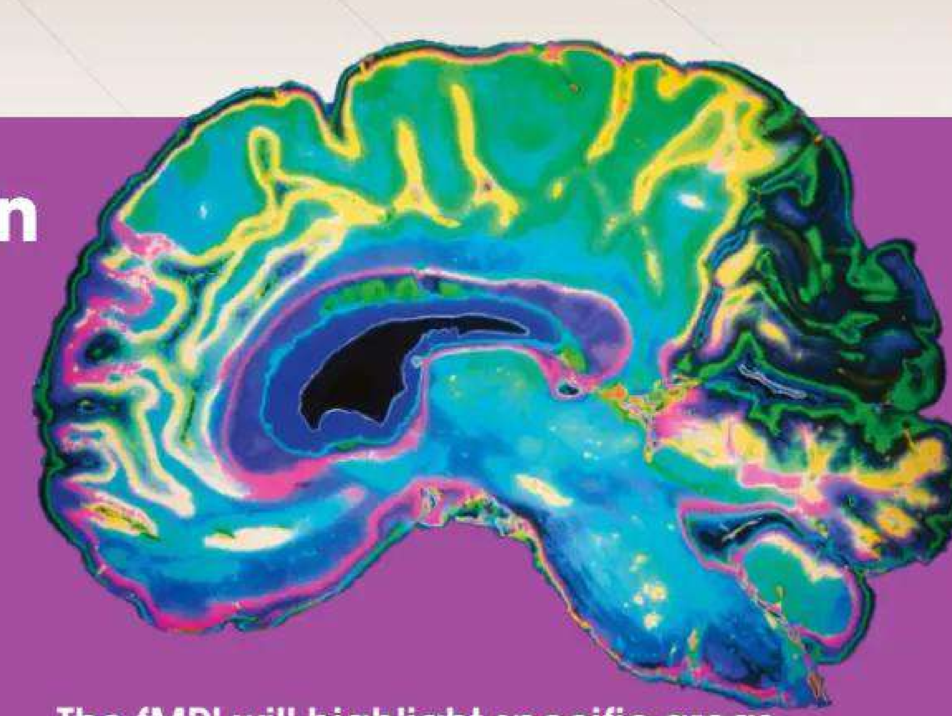
Victim location

By moving around the scene, it's possible to appreciate the exact locations of the various suspects, victims and witnesses.

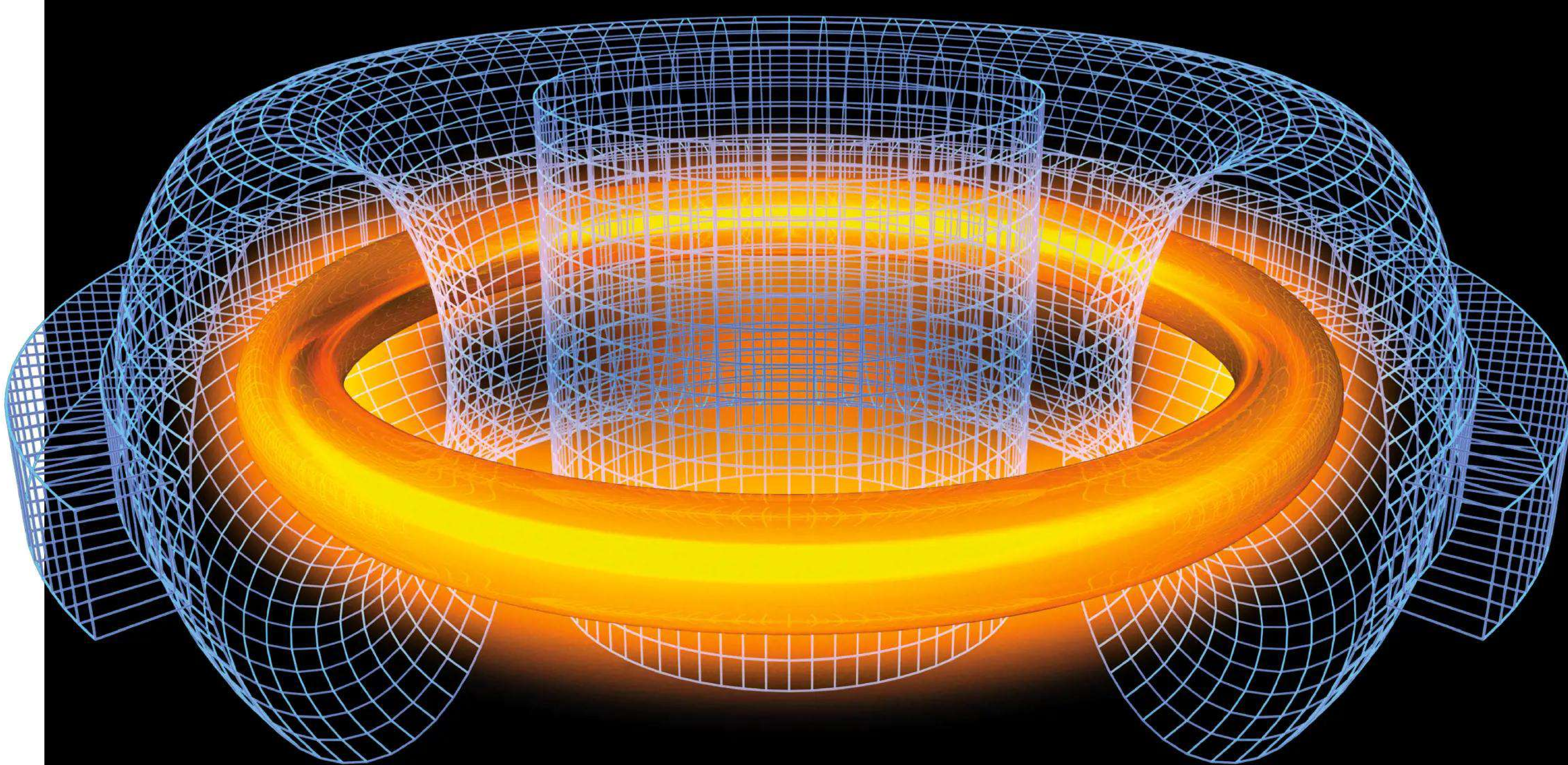
> "Telling lies increases blood flow to the brain"

How lies can be 'seen' in the brain

Researchers claim to have found the gold standard in lie detection, by monitoring the brain with functional magnetic resonance imaging (fMRI). Research has shown that telling lies increases blood flow to the brain, which in turn increases oxygen levels. This increased oxygen level causes the brain to brighten in the fMRI image. Scientists believe this method is much harder to cheat than a traditional polygraph, as the fMRI continually tracks changes in the brain. Polygraphs only measure typical stress responses and link them to the chance of a subject answering untruthfully.



The fMRI will highlight specific areas in the brain to show increased blood flow



Next-gen energy

The amazing new sources of power that could replace fossil fuels and turn our planet green

Currently, our planet gets most of its power from coal, oil and gas. These so-called fossil fuels were formed from the remains of living organisms existing millions of years ago, and when burned, they release heat energy that can be turned into electricity. However, they are also very harmful to the environment, as burning fossil fuels gives off a lot of carbon dioxide, a greenhouse gas that contributes to global warming.

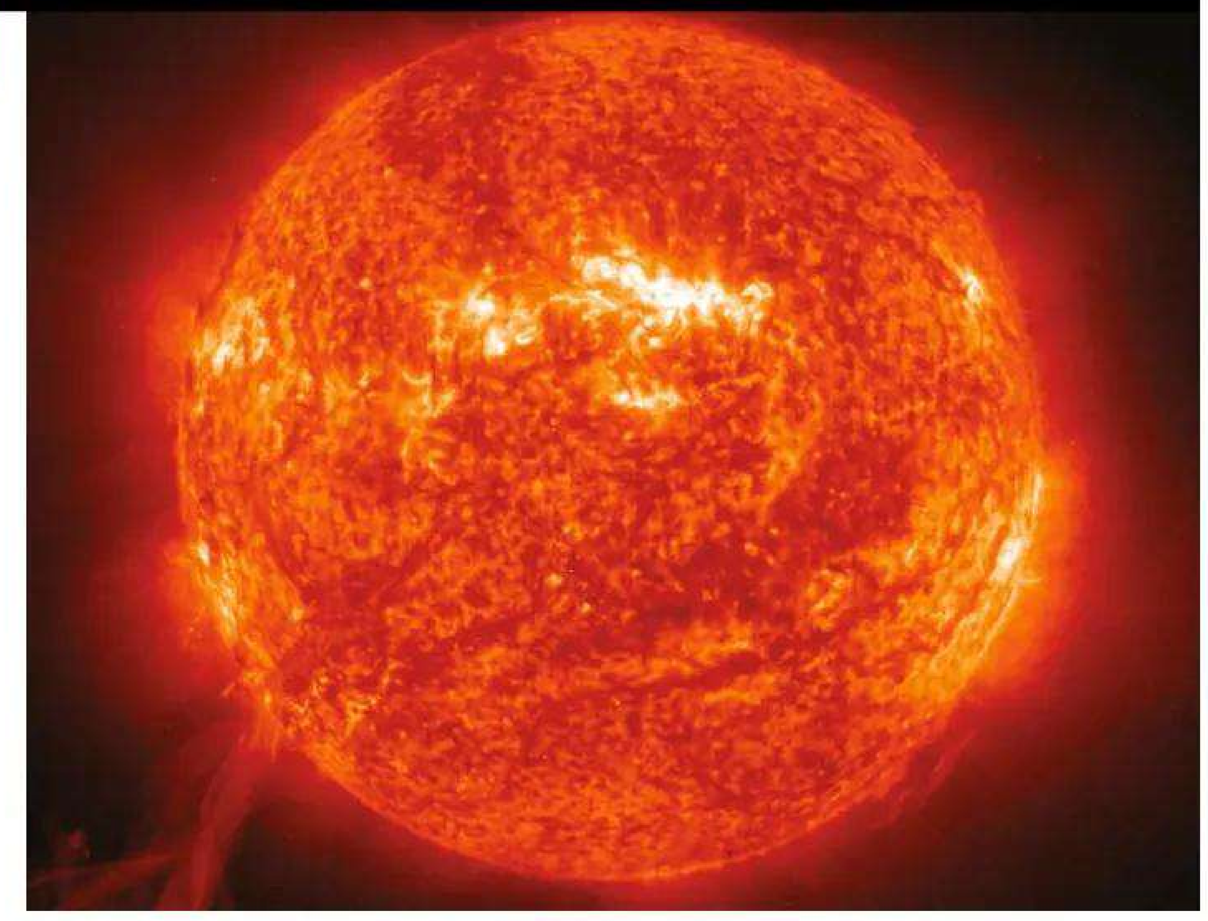
As the Sun's energy beats down on Earth, approximately 70 per cent of it gets absorbed by the land and oceans, while 30 per cent is reflected back into space. However, the 70 per cent absorbed by Earth is eventually radiated back out into the atmosphere in the form of infrared energy. Greenhouse gases then absorb this energy, but also emit heat in the process, which warms the Earth's surface and lower atmosphere.

This process occurs naturally and is what keeps the planet warm enough for living things to survive on it. However, a dramatic increase in greenhouse gas emissions since the Industrial Revolution has also caused a big rise in the average surface temperature of the Earth.

This in turn has caused the world's glaciers and ice shelves to melt faster, which will lead to a rise in sea levels resulting in the flooding of low-lying areas of coast. An increase in global temperatures fuels more fierce and devastating tropical storms and hurricanes, and could also trigger severe droughts in some parts of the world.

Even if burning fossils didn't have this destructive power, it would still be important for us to find alternative sources of energy. Although fossil fuels are technically renewable, as they are made from living organisms, that fact we are using them up at a much faster rate than they can be formed means we will eventually run out.

Some renewable sources of energy, such as solar, wind and hydroelectric power, are already being used, but these come with their own problems that prevent them from replacing fossil fuels altogether. However, as we continue to find innovative new ways to harness unused energy, our planet could soon become a green, self-powered machine.



Emergence of fusion power

Generating energy by mimicking the Sun could be the most efficient renewable source yet

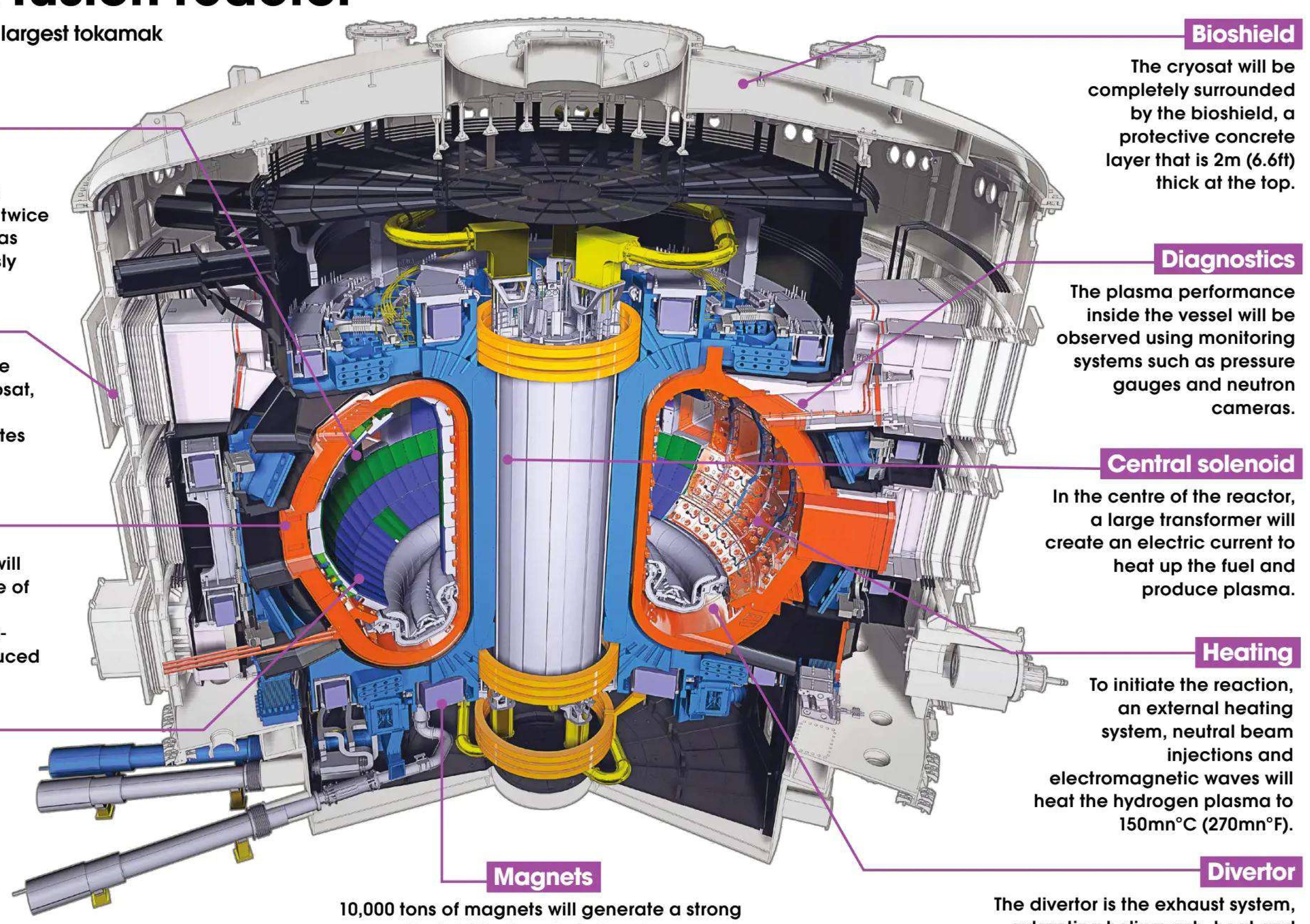
Stars such as our Sun produce huge amounts of energy using a process known as fusion. When exposed to extreme heat and high pressures in the star's core, hydrogen atoms are stripped of their electrons to expose their nuclei. This soup of nuclei and electrons is known as plasma, the fourth state of matter. When plasma is heated, the hydrogen nuclei move quickly and collide, fusing together to produce helium and a great deal of energy.

Due to the clean and efficient nature of this process, scientists have now developed a way to replicate it here on Earth, in the hope that it could eventually eliminate the need for fossil fuels. To do this, they have built enormous fusion reactors, which use magnetic fields to produce temperatures of 150 million degrees Celsius (270 degrees Fahrenheit), ten times hotter than Sun's core, and control plasma within a ring-shaped chamber called a tokamak. The fuels used in the reactor are the hydrogen isotopes deuterium, extracted from water and tritium, produced from lithium found in the Earth's crust. Our current supply will last for millions of years, and just one kilogram (2.2 pounds) can provide the same amount of energy as 10,000 tons of fossil fuel. Plus, the main by-product of fusion power is a small amount of helium, which will not pollute the atmosphere.

Although the technology is already in place to create fusion power, current fusion reactors consume more energy than they produce. The challenge now is to build a reactor that is big enough to serve as a working power plant, and the ITER project in France is the first step.

The ITER fusion reactor

Plans for the world's largest tokamak



8,000 tons of tokamak
The 19 x 11m (62 x 36ft) vacuum vessel will be twice as large and 16 times as heavy as any previously built tokamak.

Cryosat
The entire vessel will be enclosed within a cryosat, essentially a giant refrigerator that insulates the superconducting magnet system.

Blanket
440 blanket modules will cover the inner surface of the vacuum vessel, protecting it from high-energy neutrons produced during the reaction.

Vacuum vessel
A double-walled stainless steel container will house the plasma particles, which will spiral around the donut-shaped chamber creating a fusion reaction.

Magnets
10,000 tons of magnets will generate a strong magnetic field that controls the plasma and keeps it away from the walls.

Bioshield
The cryosat will be completely surrounded by the bioshield, a protective concrete layer that is 2m (6.6ft) thick at the top.

Diagnostics
The plasma performance inside the vessel will be observed using monitoring systems such as pressure gauges and neutron cameras.

Central solenoid
In the centre of the reactor, a large transformer will create an electric current to heat up the fuel and produce plasma.

Heating
To initiate the reaction, an external heating system, neutral beam injections and electromagnetic waves will heat the hydrogen plasma to 150mn°C (270mn°F).

Divertor
The divertor is the exhaust system, extracting helium ash, heat and other impurities from the vessel.

Renewable vs non-renewable energy

What will we do when all the fossil fuels run out?

We have already discovered lots of new sustainable sources of energy in our mission to replace fossil fuels, and it's likely we will discover several more as science and technology progresses. However, renewable sources currently only supply about ten to 20 per cent of our energy needs, as obstacles such as cost and efficiency mean we are still relying on coal, oil and gas a great deal. As with most forms of technology, it's likely that cost will decrease and efficiency will increase over time, but what else is stopping us from switching to solar, wind and all the other renewable sources available?

Sources of energy

The pros and cons of all our available energy options

Biomass

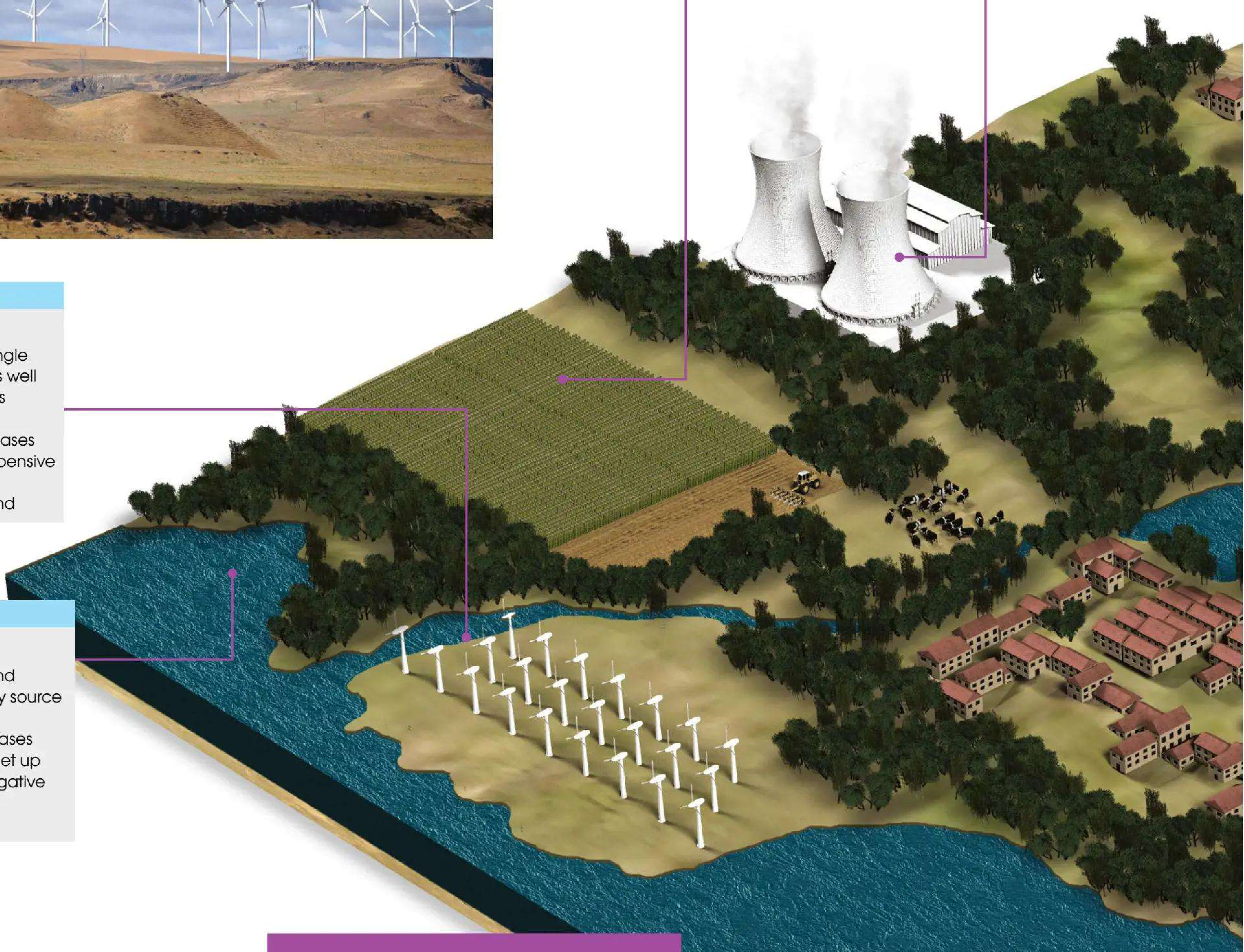
(renewable)

PRO: Can provide electricity and fuel
PRO: Cheap and abundant source of energy
CON: Gives off CO_2 when burned
CON: Only renewable if crops are replanted

Nuclear power plant

(non-renewable)

PRO: Raw materials are efficient and relatively cheap
PRO: Does not give off greenhouse gases
CON: Nuclear waste is highly toxic
CON: Nuclear reactors are expensive to run



Wind farm

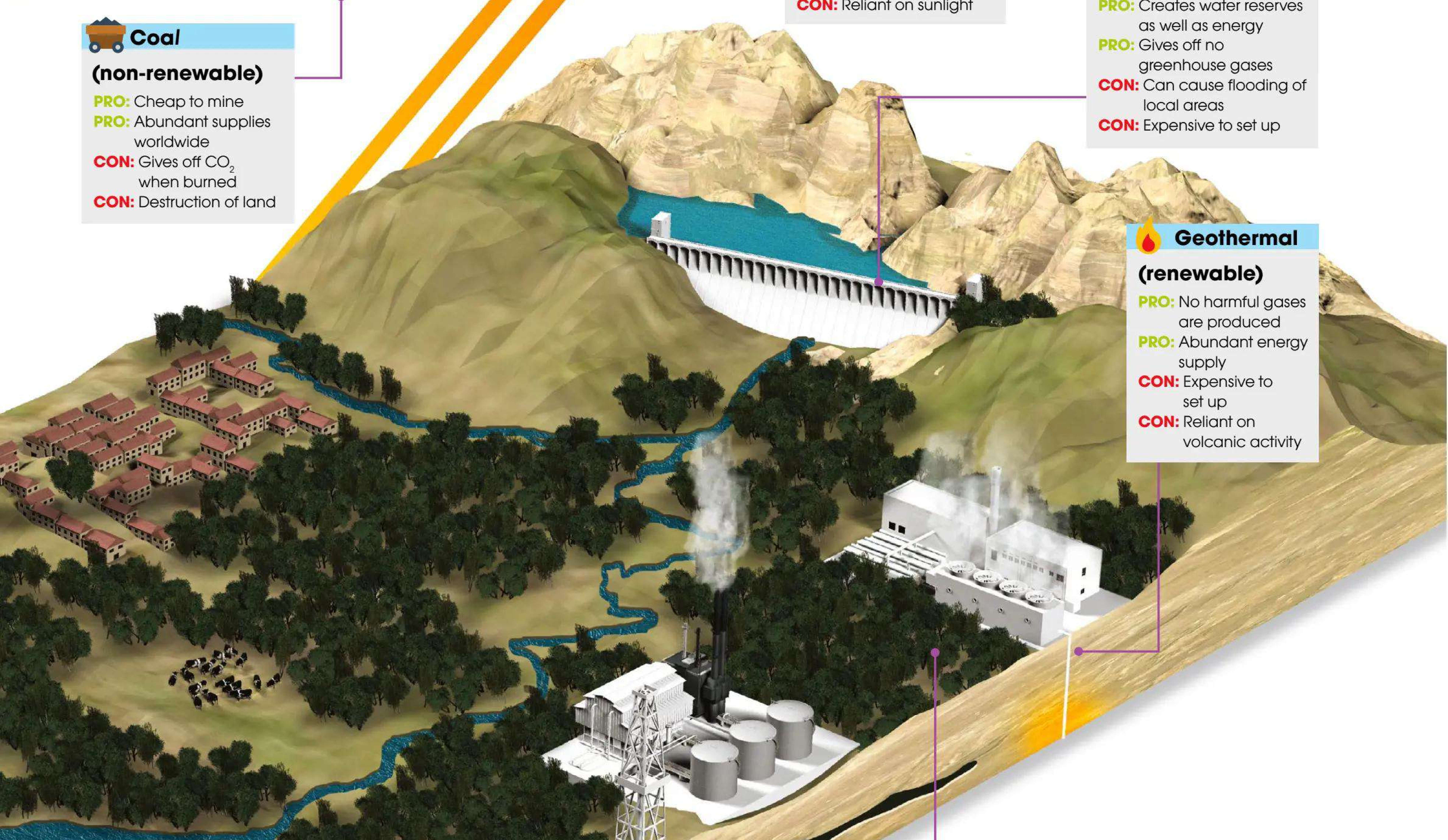
(renewable)

PRO: Can power single households as well as entire towns
PRO: Gives off no greenhouse gases
CON: Noisy and expensive to set up
CON: Reliant on wind

Tidal

(renewable)

PRO: Predictable and reliable energy source
PRO: Gives off no greenhouse gases
CON: Expensive to set up
CON: Can have negative effects on the environment



Solar

(renewable)

PRO: Solar panels are quiet and low maintenance
PRO: Gives off no greenhouse gases
CON: Panels are expensive to manufacture
CON: Reliant on sunlight

Hydroelectric

(renewable)

PRO: Creates water reserves as well as energy
PRO: Gives off no greenhouse gases
CON: Can cause flooding of local areas
CON: Expensive to set up

Coal

(non-renewable)

PRO: Cheap to mine
PRO: Abundant supplies worldwide
CON: Gives off CO_2 when burned
CON: Destruction of land

Geothermal

(renewable)

PRO: No harmful gases are produced
PRO: Abundant energy supply
CON: Expensive to set up
CON: Reliant on volcanic activity

Oil

(non-renewable)

PRO: Easy to extract and distribute
PRO: Powerful and versatile fuel
CON: Gives off CO_2 when burned
CON: Difficult and costly to find new sources

Gas

(non-renewable)

PRO: Cleaner than oil or coal
PRO: Easily transported
CON: Gives off CO_2 when burned
CON: Dangerous to work with

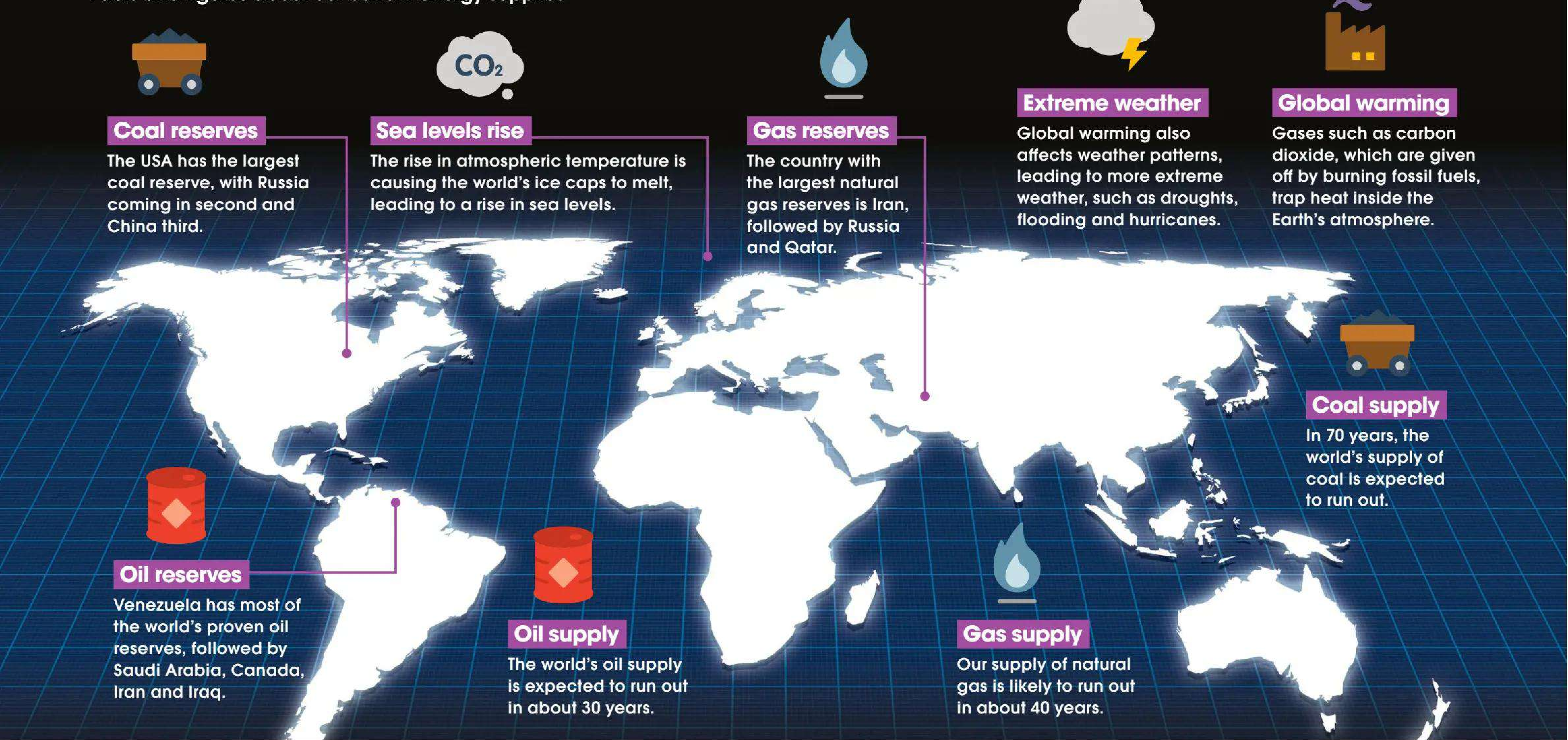
Timber

(renewable)

PRO: Cheap and abundant source of energy
PRO: Sustainable, long term source
CON: Gives off CO_2 when burned
CON: Only renewable if trees are replanted

Why do we need renewable energy?

Facts and figures about our current energy supplies



Limitations of green energy

What's holding us back from becoming a fossil fuel-free planet?

Despite the infinite supply of energy available from renewable sources, we still rely heavily on fossil fuels. Unfortunately, there are many issues that still need to be overcome before we can become completely green.

One of the main obstacles is cost, as the infrastructure required for most renewable energy sources is expensive. Solar panels, wind turbines, hydroelectric dams, tidal barrages and nuclear fusion plants are all expensive to build and storing any excess energy they produce can also be costly.

The reliance on unpredictable weather is another major issue. Wind, for example, is very inconsistent, and solar energy is only harvested in significant amounts during clear daylight hours. Therefore, fossil fuel energy is still required as a back-up.

At the moment, technology used to harvest renewable energy isn't particularly efficient. Vast areas of land or sea need to be covered with solar panels or wind turbines to generate the same amount of power as non-renewable sources. This can generate opposition from local residents, as some people believe wind farms spoil the countryside. Local ecosystems can also be negatively affected by renewable energy sources. For example, hydroelectric dams disturb the flow of rivers, disrupting native wildlife and local settlements, and tidal barrages can be harmful to marine life.

Of course, some sustainable solutions are severely restricted by location anyway. For example, geothermal energy can only be produced near areas of volcanic activity, and tidal energy requires strong tides.


Wind turbines can operate in wind speeds up to ca 60m/s (197ft/s). If gales are any stronger they shut down to avoid damage

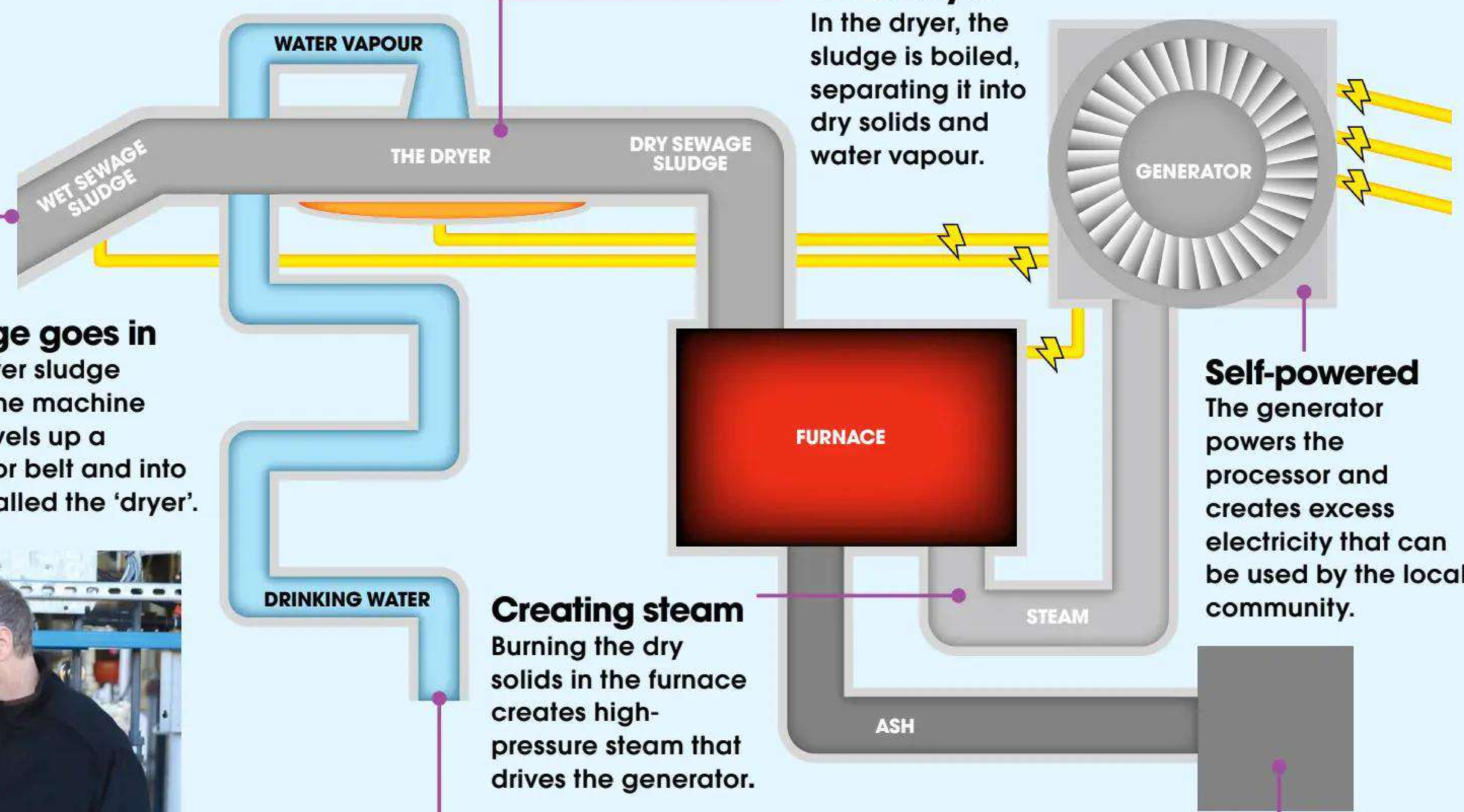

Hydroelectric power is reliant on rainfall, and causes flooding of land that can damage human and animal habitats


Solar panels usually only convert about 10-20% of the energy that reaches them into electricity, and become less efficient in very high temperatures

Sewage as power

The incredible poo-powered machine backed by Bill Gates

The Janicki Bioenergy Omni Processor is a type of sewage treatment plant that also creates renewable energy. It serves as a safe repository for human waste, preventing the sewage from being dumped into rivers or oceans, and providing clean drinking water and electricity without releasing harmful greenhouse gases.



In the dryer
In the dryer, the sludge is boiled, separating it into dry solids and water vapour.

Sewage goes in
Wet sewer sludge enters the machine and travels up a conveyor belt and into tubes called the 'dryer'.

Self-powered
The generator powers the processor and creates excess electricity that can be used by the local community.

Creating steam
Burning the dry solids in the furnace creates high-pressure steam that drives the generator.

Drinking water
The water vapour is run through a cleaning system to produce pure water that is safe to drink.

Leftover ash
The dry solids are fed into a furnace, where they are turned into ash that is pathogen-free.

Sunshine-powered water purifier

The solar-powered machine that makes contaminated water safe to drink

The Desolenator uses energy from the Sun to turn dirty or saltwater into distilled water.

Solar purification utilises photovoltaic cells to generate enough power to heat water that is unsafe to drink, such as seawater. The resulting steam vapour is then collected as distilled water. Excess electricity generated from the solar panels is then stored in batteries.

The purpose of this method of water filtration is to provide water-stressed towns and villages with a cheap, reliable and convenient source of hydration. In November 2020, Desolenator and the Carlsberg Group announced they are partnering to create clean drinking water for a town of 4,000 in West Bengal, India.

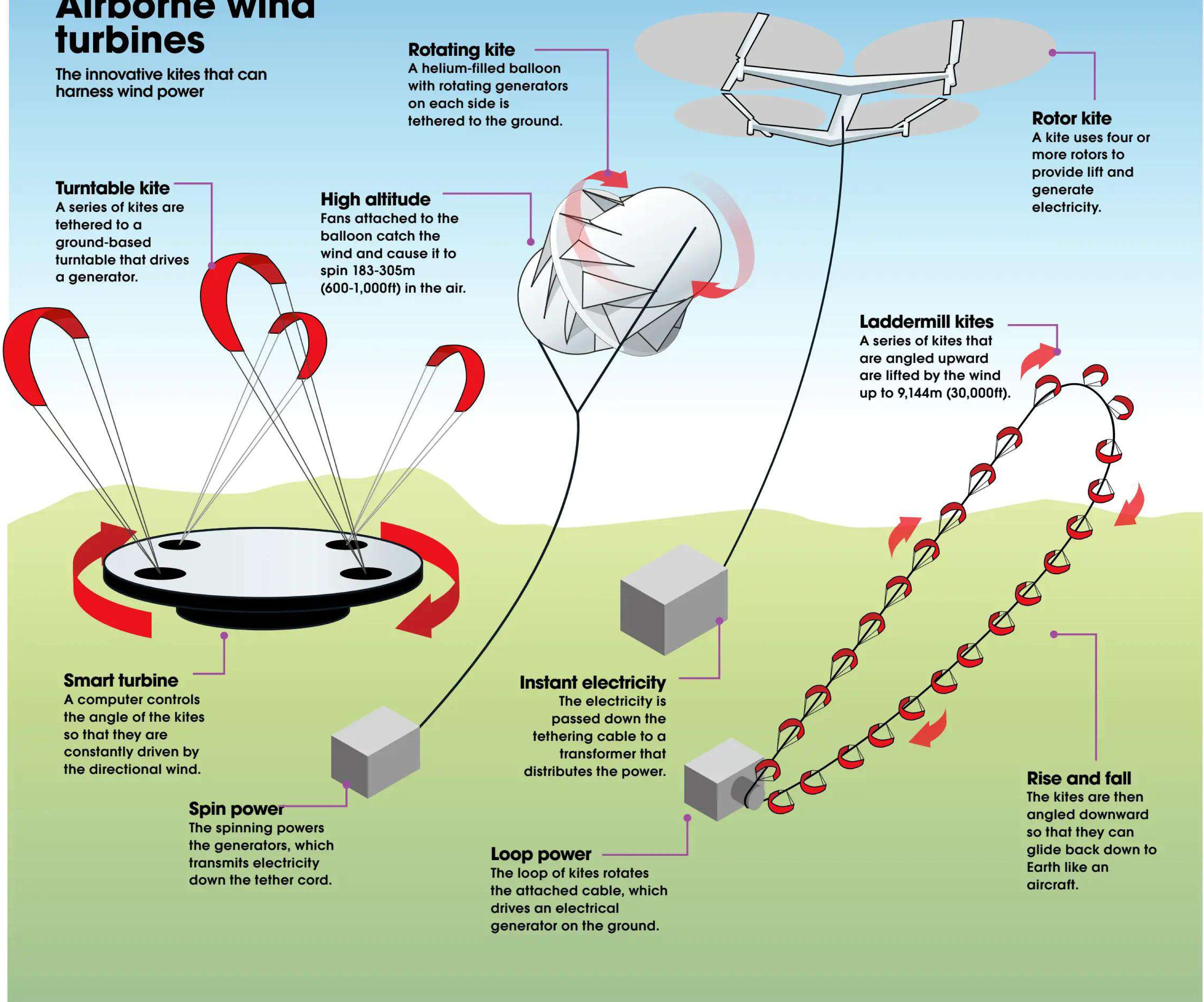
Kite power

Catching the wind and harnessing its power

Traditional wind turbines are typically less than 200 metres (656 feet) tall, using winds that are weaker and more inconsistent than at higher altitudes. To harness the energy from this more powerful wind, many companies are developing various forms of airborne wind turbine that have the added benefit of being out of sight and earshot.

Airborne wind turbines

The innovative kites that can harness wind power



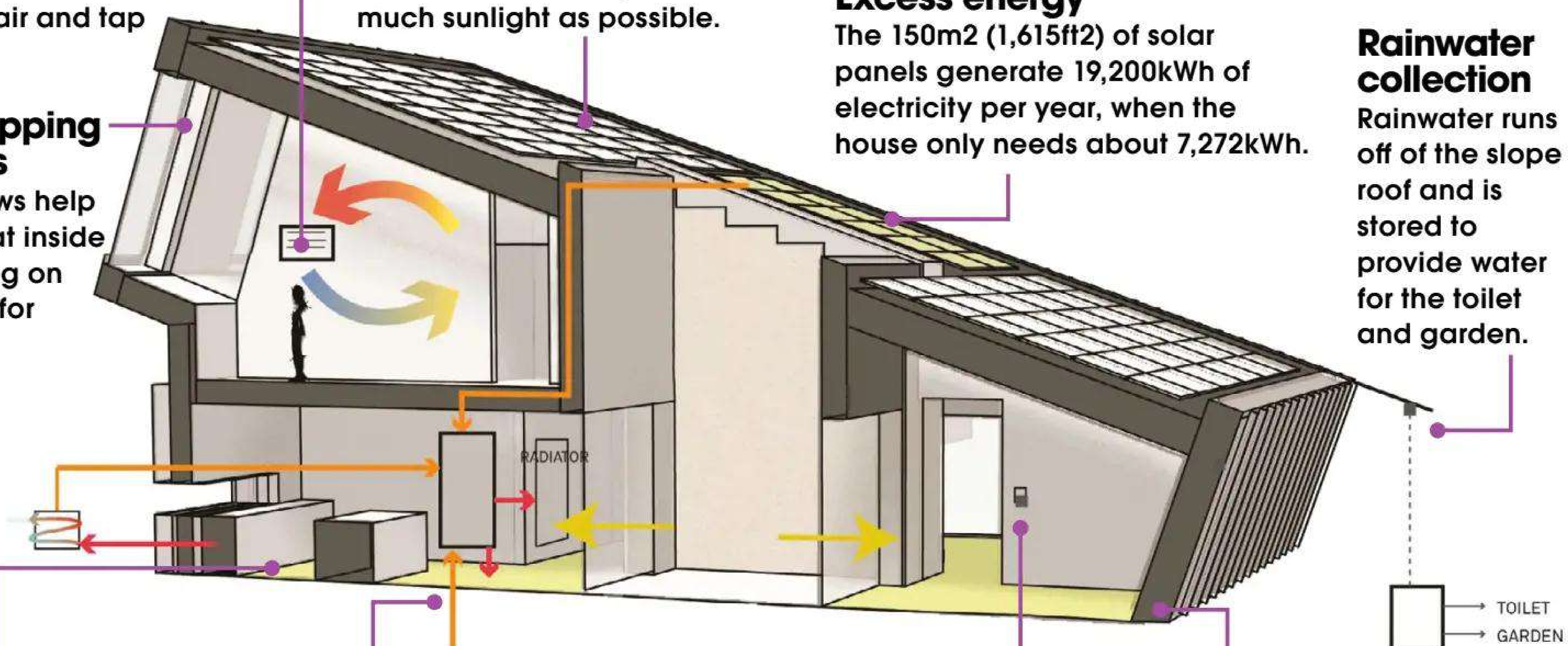
Eco-house

The family home that generates more energy than it needs

The ZEB Pilot House, created by Norwegian architect firm Snøhetta, uses solar and geothermal power to produce three times more energy than it needs. In fact, the surplus energy it generates is enough to power an electric car year-round. The building, situated in Larvik, Norway, is big enough to house a family.

ZEB Pilot House

Tour the ZEB Pilot House



Circulating heat
A heat exchanger uses excess heat from indoor air to heat the incoming air and tap water.

Solar panel roof
The roof, clad with solar panels, is sloped 19 degrees toward the southeast to capture as much sunlight as possible.

Excess energy
The 150m2 (1,615ft2) of solar panels generate 19,200kWh of electricity per year, when the house only needs about 7,272kWh.

Rainwater collection
Rainwater runs off of the slope roof and is stored to provide water for the toilet and garden.

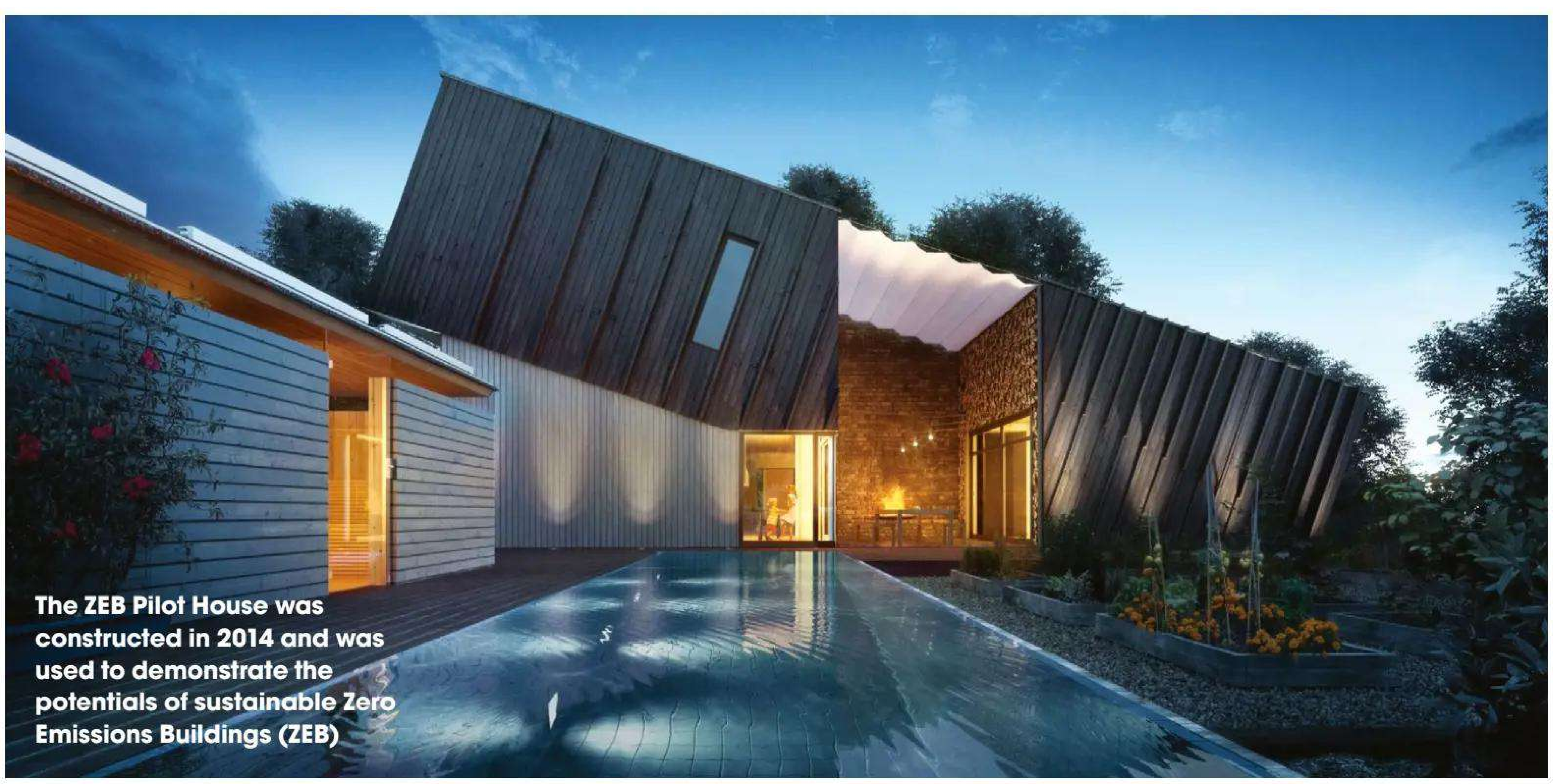
Heat-trapping windows
The windows help to trap heat inside the building on cold days for greater efficiency.

Heating system
The house features efficient under-floor heating, and just one radiator on each floor.

Geothermal energy
An underground well harvests geothermal energy, using pressurised steam from hot water to power a generator.

Smart control
The interior light and air is automatically controlled by smart monitors based on usage and need.

Good thermal mass
High-density building materials, such as concrete and brick, absorb and store heat energy, stabilising the temperature.



The ZEB Pilot House was constructed in 2014 and was used to demonstrate the potentials of sustainable Zero Emissions Buildings (ZEB)

Harnessing the power of salt & water

Since the 1950s, scientists have been developing the use of 'blue energy' to generate electricity from salty water.

The science stems from the discovery that at the point where freshwater meets the salty sea, such as at estuaries and deltas, the interacting waters have the potential to generate amounts of electricity through the natural process of osmosis.

"This increase in pressure can be used to power a turbine and generate electricity"

When salt-rich seawater meets diluted freshwater, the waters diffuse quickly to balance out the salinity. When a semi-permeable membrane is placed between these two types of water, something called pressure-retarded osmosis can be achieved. As the freshwater moves through the membrane and mixes with the seawater, it increases the pressure on the seawaters side of the membrane. This increase in pressure can be used to power a turbine and generate electricity.

Another method of harnessing energy from mixing tides is adding a second membrane either side of the freshwater and collecting the current generated by positively charged sodium ions in the saltwater as they move through the membrane. Over the years, energy companies like the myFC Fuel Cell System have utilised this natural process to create innovative energy solutions.

The PowerTrekk portable charger generates its own electricity on the go using water and salt

People power

Could our bodies soon become our own renewable power station?

The human body is one big energy factory. Calories go in and they power our organs and muscles, generating excess heat. Simply going for a walk could generate 163 watts of power, but the big challenge is working out how to turn this into usable energy.

Scientists are exploring lots of innovative ways to harness human power, and one method involves piezoelectricity, which can be produced from the pressure applied to a surface through motions such as walking.

When pressure is applied to an object containing atoms or molecules arranged in a very orderly way, also known as crystals, the charges are forced out of balance. The compressed side gains a positive charge while the opposite develops a negative charge, and when the pressure is relieved an electric current flows between them, which can be stored and used as a power source. Although this is proven to work, it only generates a very small amount of electricity, unfortunately insufficient for powering most electronic devices.

Scientists have also uncovered a way to generate electricity from clothes. Using nylon fibres, a group of researchers from the University of Bath, the Max Planck Institute for Polymer Research, Germany, and the University of Coimbra in Portugal have made a breakthrough. Scientists have been aware of the piezoelectric properties of nylon since the late 1900s, but until November 2020 the potential of its ability to generate electricity were not realised. In its raw form, nylon is a white powder that can be incorporated into a whole host of other products, like packaging and clothing, but on its own, it can be transformed into piezoelectric fibres.

Although the technology is still in its infancy, the hope is that our clothes will one day charge our devices. For example, just walking in a shirt woven with piezoelectric fibres could generate enough electrical charge to a battery.

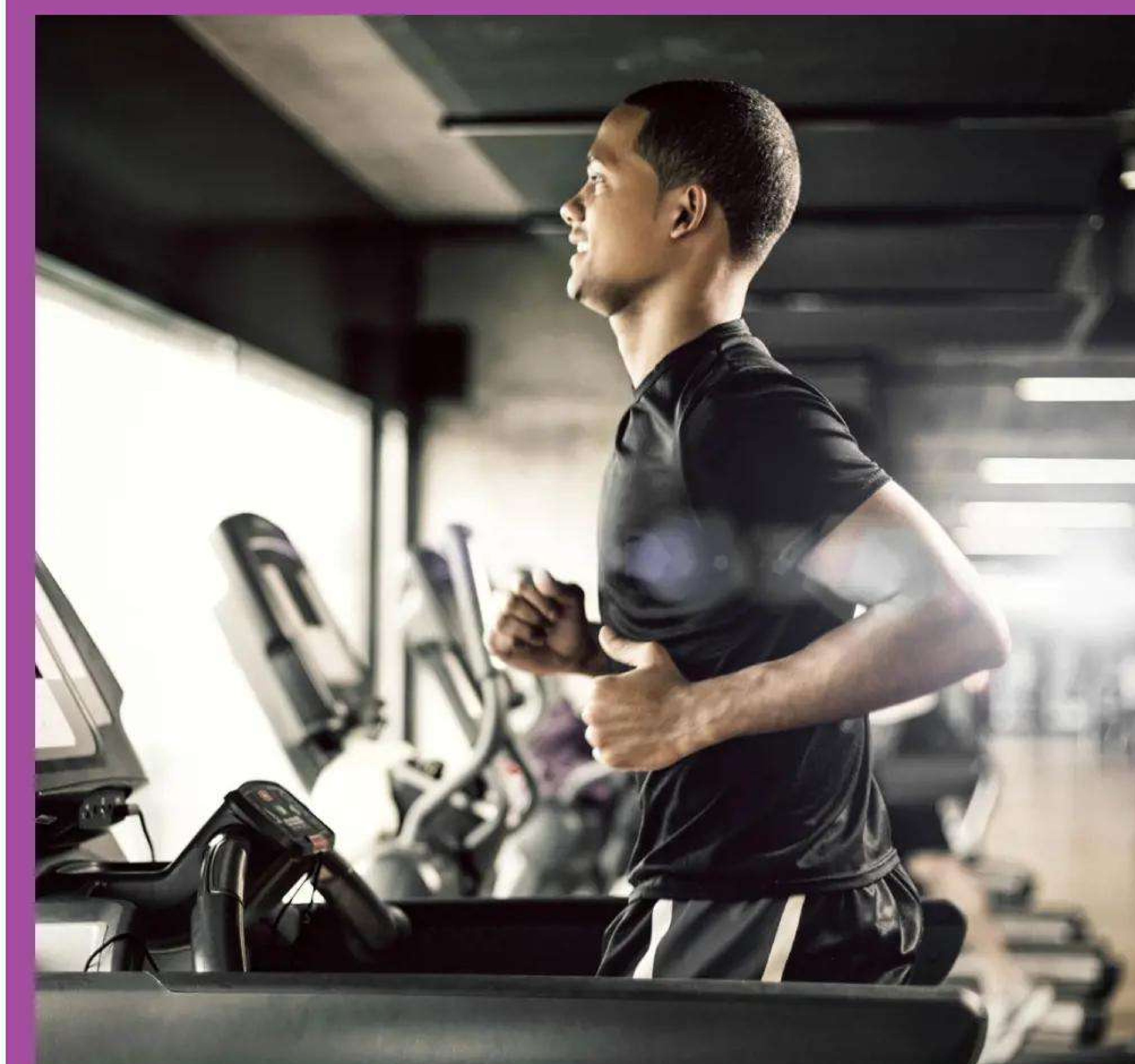
Energy from exercise

Anyone who has started a workout regime will know that exercising requires a lot of energy, but you may not have realised that it can generate energy, too.

Eco-conscious fitness companies likeSportsArt are transforming both the way we exercise and how we generate electricity. For example, when using one of the company's ECO-POWR™ treadmills, the device will draw on a small amount of electrical power from the main supply. As your exercise intensifies, it will stop consuming electricity and run off the energy produced from the exercise itself.

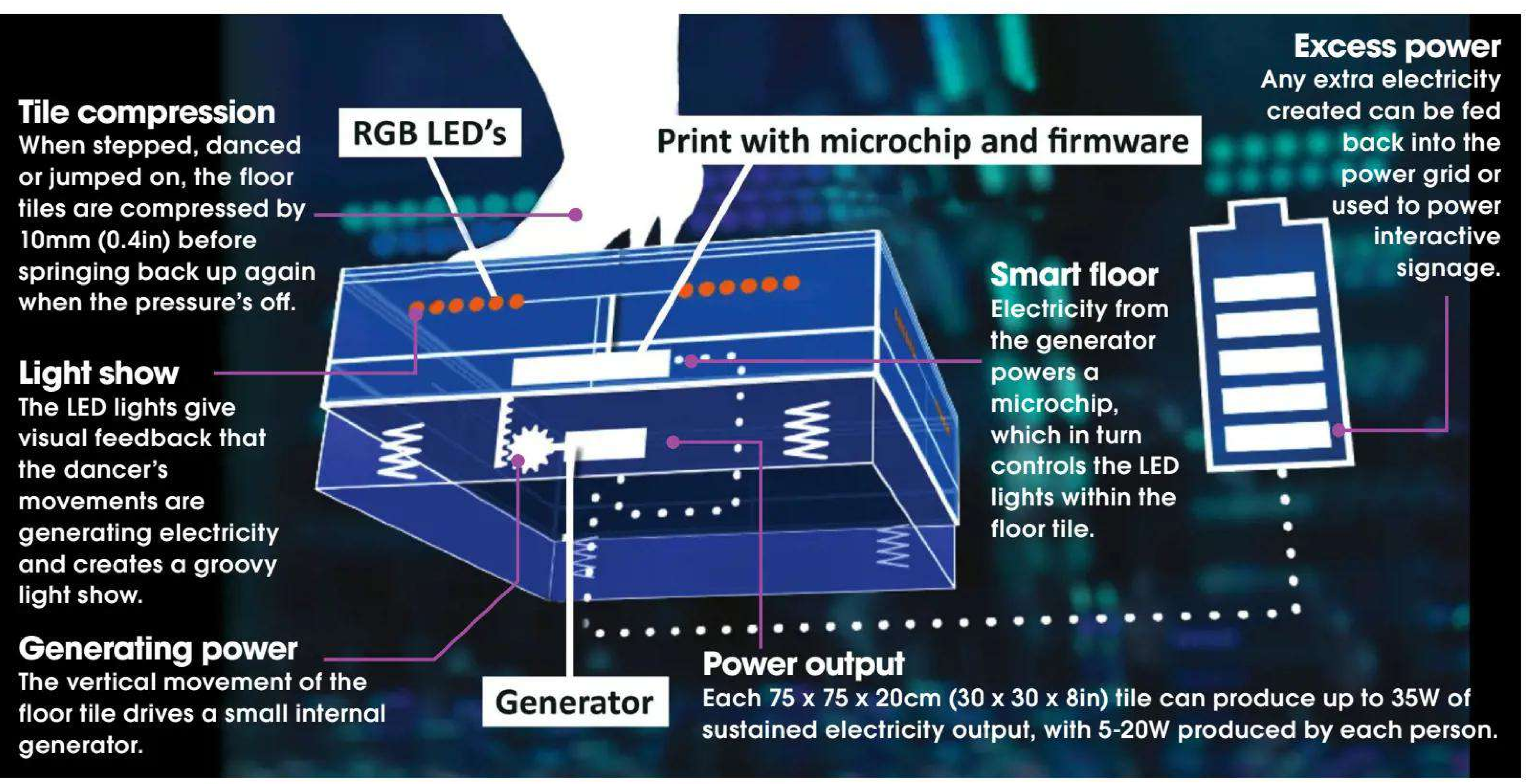
The human movement on the equipment is captured by a generator and passed through a micro-inverter to transform it into electrical energy and then fed back into the machine.

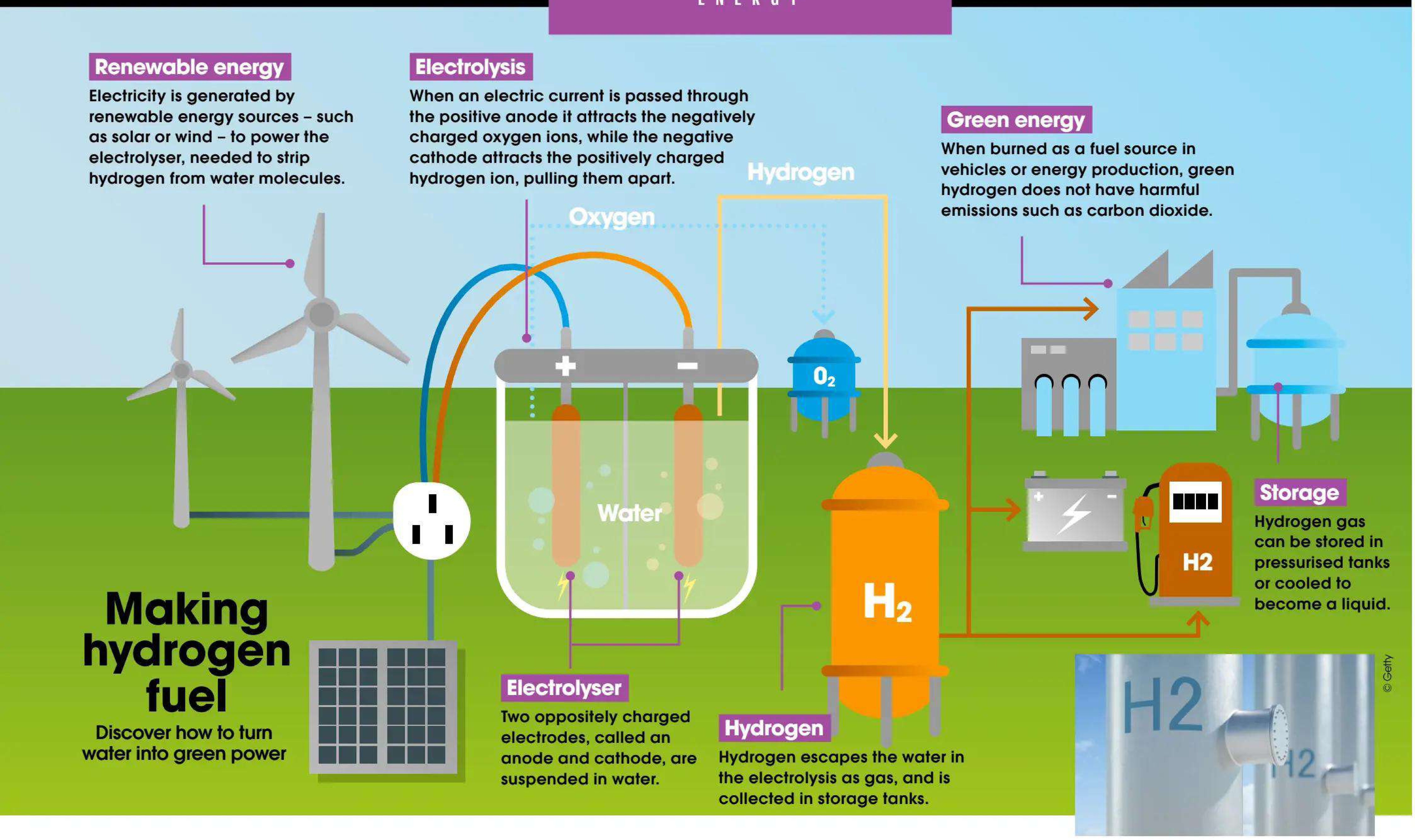
SporsArt report that their patented ECO-POWR™ technology equipped gym equipment can generate 220 Wh of electricity per hour. Green energy innovation such as these could be the future in harvesting human-made energy.



Energy floors

Rotterdam-based company Energy Floors uses an electromechanical system to turn kinetic energy into electricity. Its Sustainable Dance Floor uses the movement of dancers to light up the ground beneath their feet. The interactive light show was designed to raise awareness of the potential of kinetic energy, and has proved popular for corporate and public events, but they have since developed a new product with more practical benefits. Their Sustainable Energy Floors are designed for areas with high footfall, such as shopping malls, sports arenas and airports. Each step onto a tile can generate between two and 20 joules of energy, which can be used to power nearby lights or signage.





Green hydrogen revolution

Green hydrogen production is gaining steam as one of the most viable clean fuel sources of the future

Scientists are continuously looking for alternative fuel sources to decarbonise the Earth. As the climate crisis grows ever more prevalent, the need to find fossil fuel alternatives has never been greater. Green hydrogen is a renewable fuel resource that will be making waves. This type of fuel can be created by breaking off hydrogen atoms that are bound to oxygen atoms in water molecules using electricity supplied by other renewable energy sources, such as solar or wind power. The harvested hydrogen can be used as a fuel source for energy production and vehicles without creating damaging pollutants or carbon dioxide.

The production of hydrogen fuel is gaining momentum in countries around the world. For example, back in 2020, plans were unveiled for the construction of a 51-acre commercial hydrogen-production hub near Glasgow, Scotland. It's estimated that the plant will initially produce 800,000 kilograms of hydrogen each year. Other countries such as Australia, the US and China are also exploring the potential of hydrogen power to produce zero-emission fuels. Germany has recently dedicated €9 million (£8 million) to green hydrogen production with the aim of becoming carbon neutral by 2050.

Solar panels are ready for a downsize with solar-powered clothing

Solar-power clothing

As well as generating energy from body heat, clothing can also harvest energy from the Sun.

Scientists at the Nottingham Trent University in the UK are developing minuscule solar cells that are flexible enough to be incorporated into clothing. These ultra-small photovoltaic panels measure three millimetres long and 1.5 millimetres wide and would not be noticeable when worn. Each of the cells is also laminated in a waterproof resin, meaning that an overall garment could be laundry proof.

Researchers found that when an array of 200 of these solar cells was embedded in a five square centimetre path of fabric, they could generate up to 80 milliwatts of power. This would be more than enough energy to charge a Fitbit.

Researchers estimate that if 2,000 of these cells were to be incorporated into a textile, it could potentially produce enough energy to charge a smartphone.

Science inspired by nature

The incredible innovations we have borrowed from animals and plants

THE WORLD AROUND US

Iridescence
The topside of the butterfly's wings appears to shimmer with vibrant blues and greens during the day.

Biological organisms on Earth have spent billions of years evolving to become masters of their environments, capable of overcoming obstacles in ingenious ways to survive in a competitive world. For example, certain parasitic wasps use their long, tubular egg-depositing organs to bore through several centimetres of solid wood, despite their inability to supply much downward force.

They achieve this by sliding the two halves of the ovipositor back and forth to penetrate further into the wood, while causing little disturbance to the surrounding area. This mechanism is quite different to drills currently used in construction and neurosurgery, but scientists have taken inspiration from this natural technique to design innovative tools, such as new steerable medical probes.

Resourceful methods such as this are abundant in the natural world, and engineers in many fields have begun to appreciate the advantages that mimicking plants and animals can bring. From construction to combat, biomimicry is helping us to discover new ways to solve old problems, and opening doors to revolutionary technologies that can push our own evolution one step further.

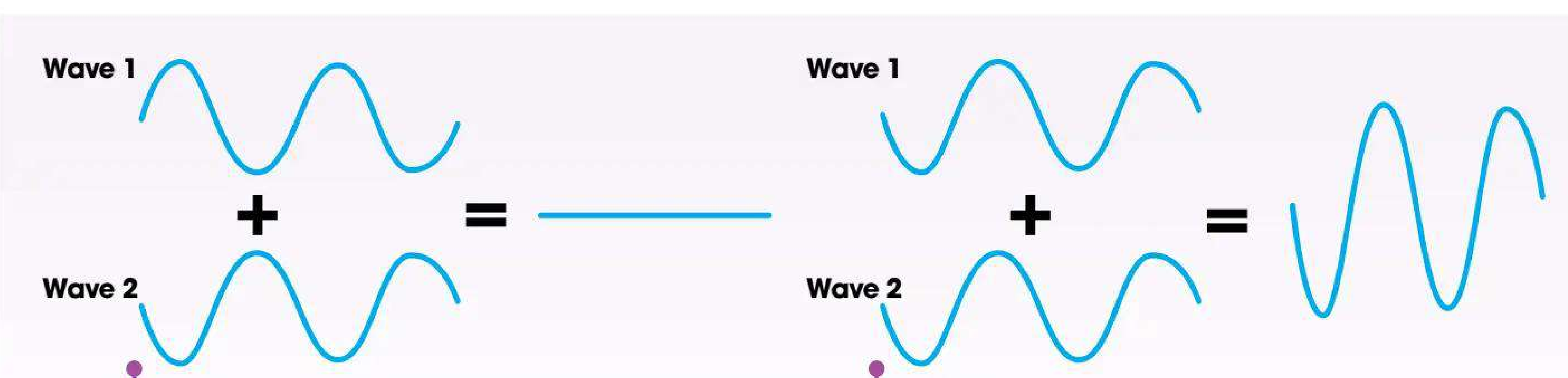
Natural colour

How a butterfly inspired a full-colour e-reader

Scales
Butterflies belong to the order Lepidoptera, which means 'scaly wings'. The topside of their wings is covered in many overlapping scales.

Cuticles
The cuticles are covered in a pattern of ridges and cross-ridges, formed from a hard substance called chitin.

Diffracted light
The pattern of ridges causes incoming light to hit different depths within the structure, and be reflected back numerous times. Blue wavelengths are intensified and reflected, while others are cancelled out.

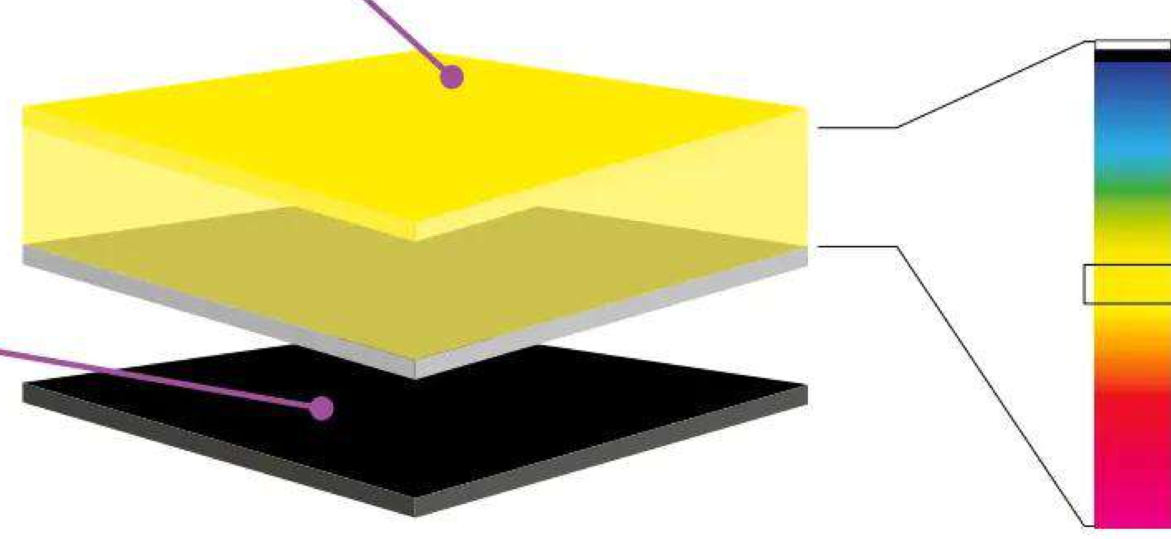


Destructive interference
Wavelengths of light with conflicting peaks and troughs will cancel one another out.

Constructive interference
Light waves where peaks and troughs align result in an amplified wavelength of colour.

Projected light
External light penetrates through the glass, and wavelengths able to escape again are projected, determining the colour.

Adjustable panels
The size of the gaps between the panels can be adjusted, allowing only the wavelengths that directly match the size of the gap to be reflected.



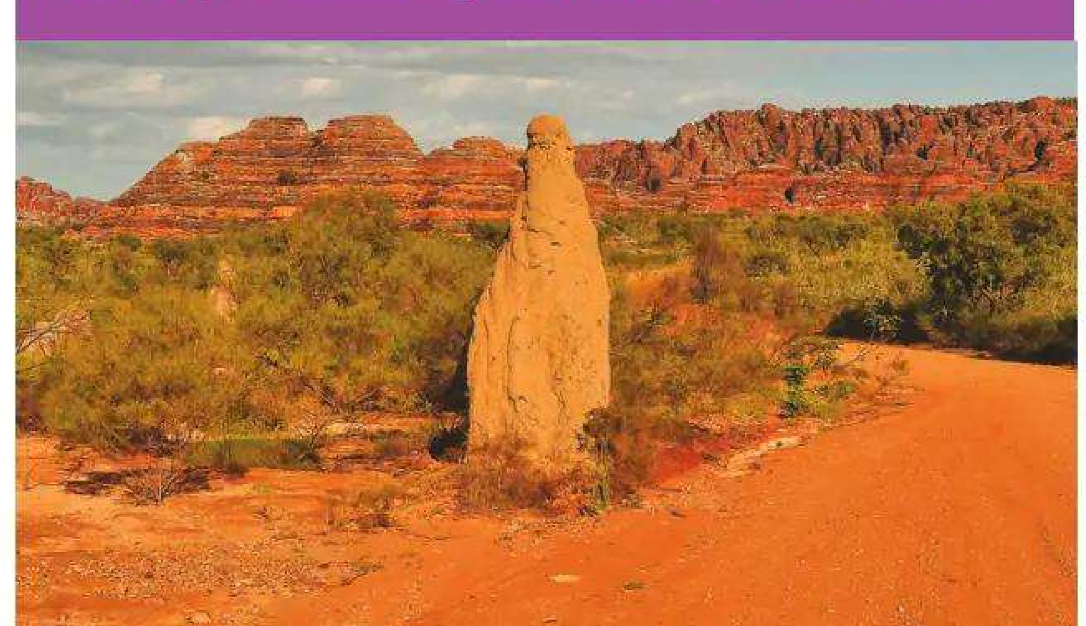
A multitude of colours
The plate gaps can be altered 1,000 times a second, allowing combinations of colours to be reflected. This enables the screen to display any colour across the visible spectrum.

Construction tips from termites

When you think of the world's greatest architects, termites probably don't spring to mind. But these creatures are capable of building huge cities complete with storage chambers, ventilation shafts and gardens, all in one mound of dirt.

The intricate network of tunnels inside the mound takes advantage of convection currents – where warm air rises and colder, denser air sinks – to maintain a stable temperature, permitting the termites to farm their primary fungal food source all year round.

This miraculous feat inspired architect Mick Pearce to design a sustainable building that is free of air-conditioning and heating units, yet remains a comfortable temperature year-round. Using the principles of the termites, the building incorporated a series of ducts and chimneys that carried heat upwards and outwards, keeping the building cool and well-ventilated.



Termites build complex structures to maintain stable temperatures in varying external heat

Artificial photosynthesis

Converting harmful gases to eco-friendly fuel with a man-made leaf

Plants have been sustaining animal life for hundreds of millions of years. By absorbing carbon dioxide, water and energy from the Sun, they produce oxygen and energy in the form of carbohydrates. Scientists have now developed an artificial leaf capable of doing the same. In fact, the artificial leaf is up to ten times more efficient at capturing solar energy than its natural counterparts. It uses catalysts to split water into oxygen and hydrogen. Specialised bacteria are then able to convert the hydrogen, along with the carbon dioxide, into liquid fuels.

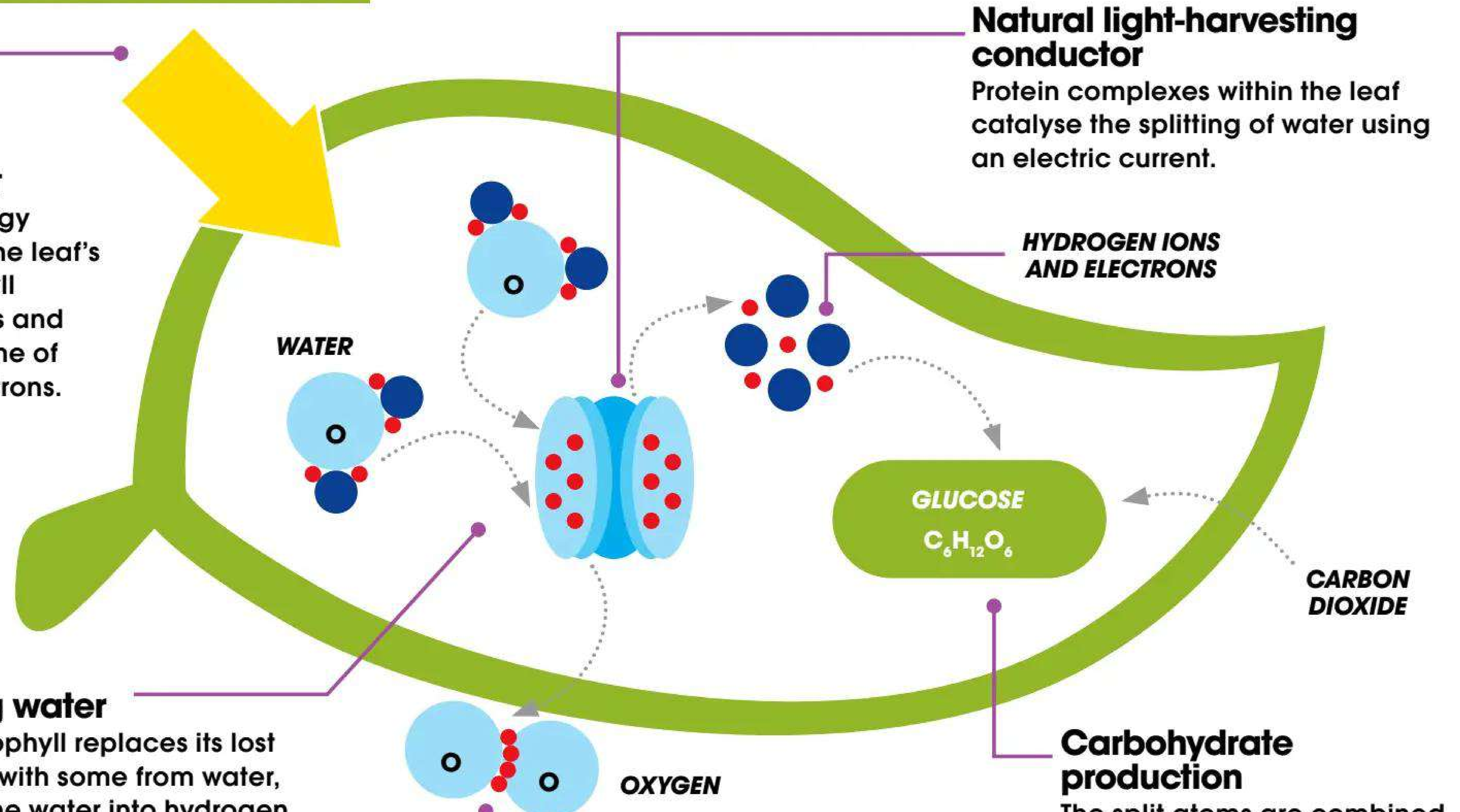
This revolutionary technology, capable of generating liquid fuel with no carbon footprint, could be an important tool in reducing our carbon dioxide emissions.

"The artificial leaf is up to ten times more efficient at capturing solar energy than its natural counterparts"

Harnessing plant power

Whether they're made in a forest or a lab, both types of leaf operate in much the same way

NATURAL PHOTOSYNTHESIS



Sunlight
Light energy reaches the leaf's chlorophyll molecules and 'frees' some of their electrons.

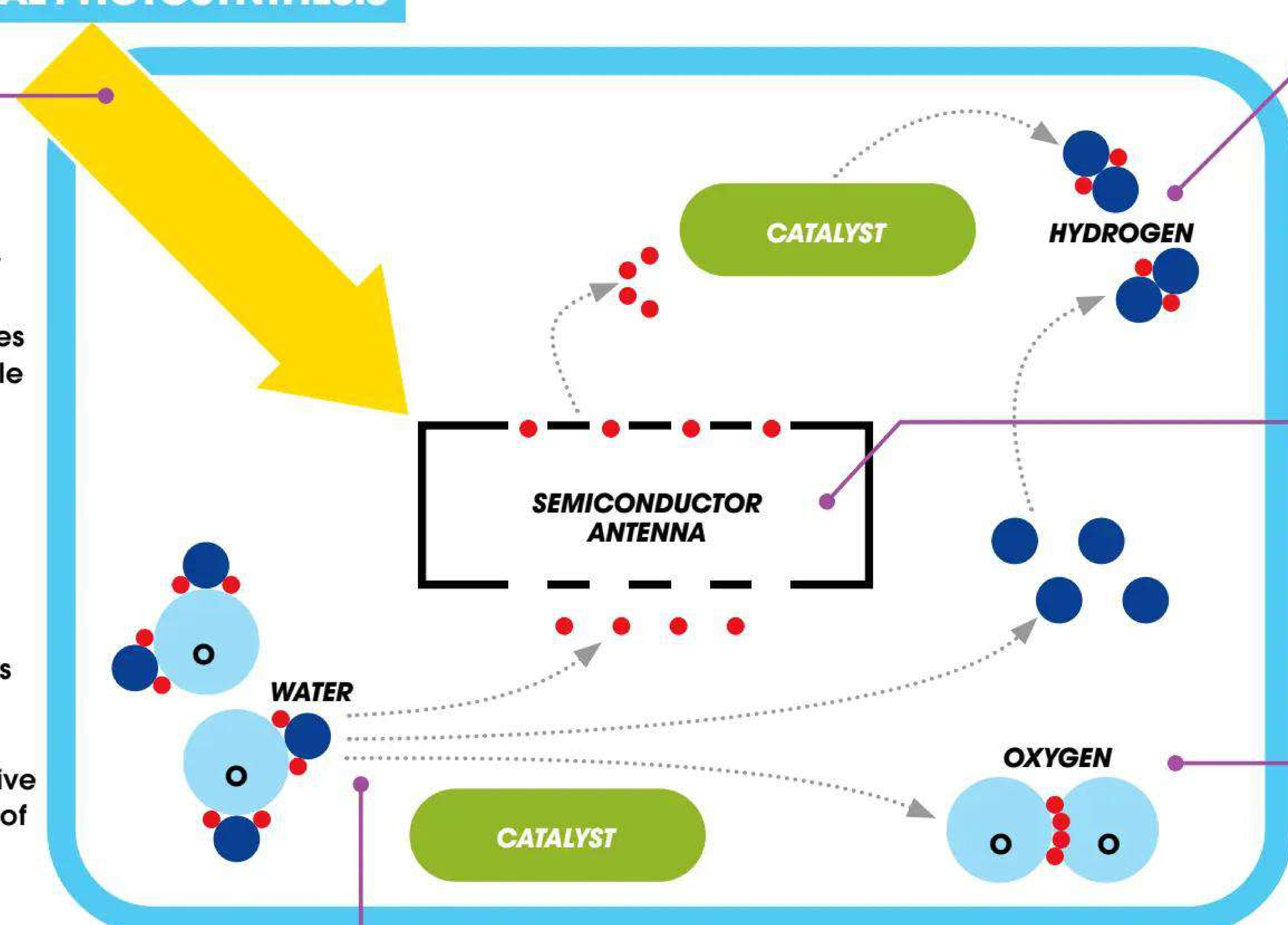
Natural light-harvesting conductor
Protein complexes within the leaf catalyse the splitting of water using an electric current.

Splitting water
The chlorophyll replaces its lost electrons with some from water, splitting the water into hydrogen and oxygen in the process.

Oxygen as a waste product
The leaf releases unneeded oxygen into the atmosphere.

Carbohydrate production
The split atoms are combined with carbon dioxide to form sugar that can be stored as an energy source.

ARTIFICIAL PHOTOSYNTHESIS



Light
Light energy is absorbed and produces 'electron-hole pairs' in the artificial conductor.

Splitting water
Two catalysts made from inexpensive materials drive the splitting of water into oxygen and hydrogen.

Renewable energy
Specialised bacteria convert hydrogen and carbon dioxide into fuel.

Light-harvesting conductor
Electrons from water 'jump' to the conductor, splitting the water molecules in the process.

Oxygen
Like its natural counterpart, the leaf releases oxygen as a byproduct.

Improving efficiency

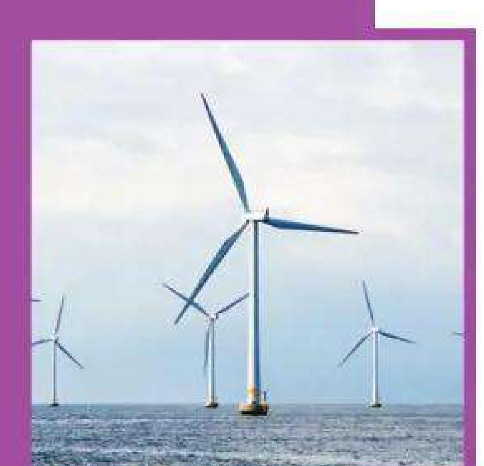
How animals have led to scientific discoveries

Velcro adhesives

Not having to tie your shoelaces was a great thing in the early school days, and we have biomimicry to thank for it. The invention was conceived after an engineer noticed how well the tiny hooks on plant burrs gripped to his dog's fur.

Superior wind turbines

Humpback whales are amazingly dextrous animals, despite their mammoth size, due to large bumps – known as tubercles – found on the edges of their flippers. This feature improves lift and reduces drag as the whale performs tricky manoeuvres, and could be incorporated into fans, aeroplanes and wind turbines.



Harvesting water in the desert

The Namib Desert is one of the driest habitats in the world, but darkling beetles have managed to survive there – by sticking their rear ends in the air and collecting water vapour. Researchers have found microscopic grooves on the beetle's forewings that help to funnel water towards their mouths. These grooves are now being incorporated into designs used for water collection devices.

Mimicking intelligence

As well as being the source of our creativity, the structure of the brain is an inspiring innovation

The human brain is often said to be the most complicated object in the known universe, encompassing around 100 billion neurons arranged in a massive network, where each neuron is connected to approximately 10,000 others. Our superior aptitude to learn, interpret and think creatively has helped us to cure diseases, place humans on the Moon, and develop helpful computer programs that surround us in our everyday lives.

Computer power and capability has improved massively in the past few decades, and today a computer can solve a mathematical problem almost instantly, much faster than the human brain. Shops, schools, hospitals and laboratories all use these machines as an integral part of their working systems.

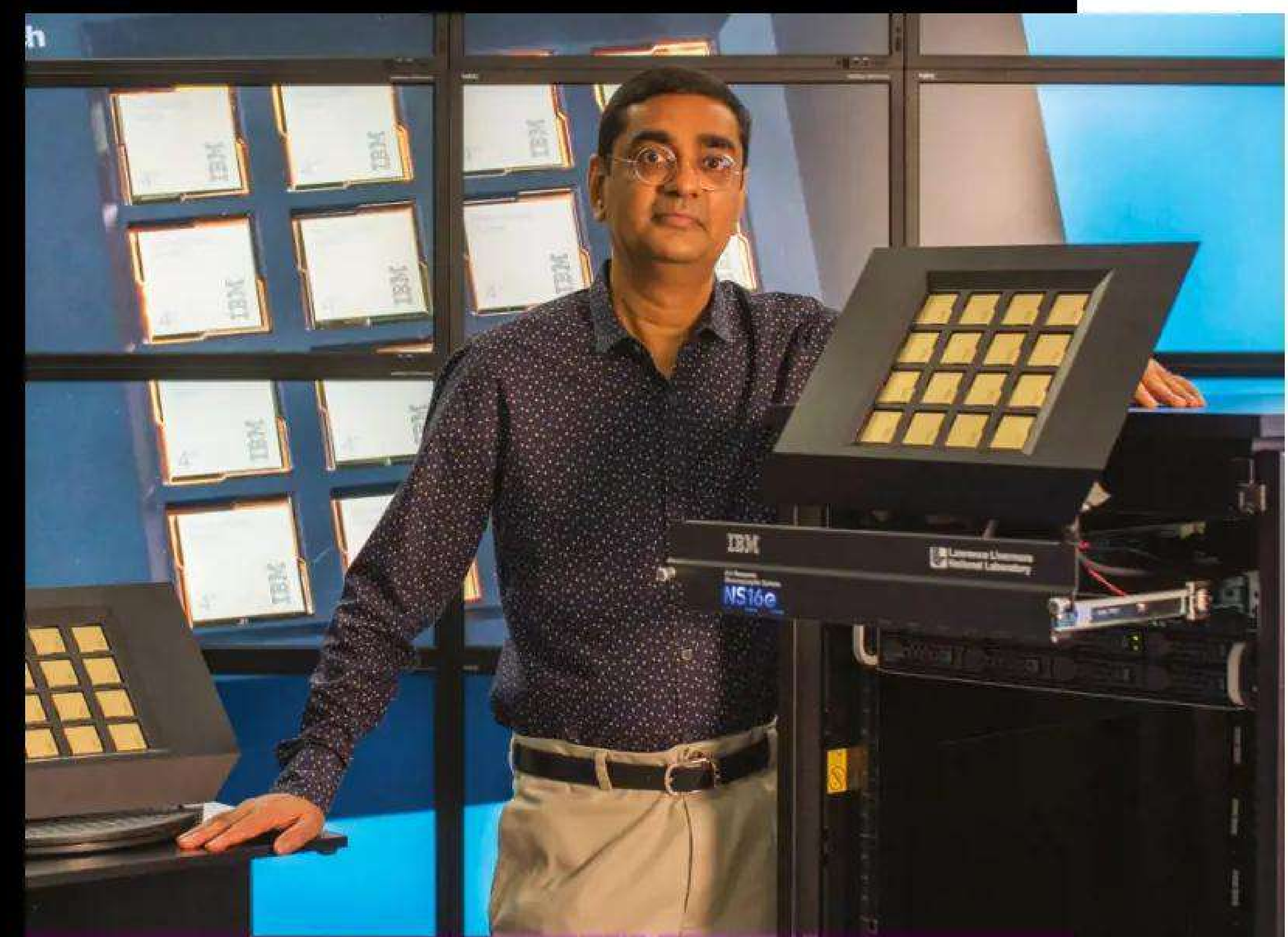
These tools are highly capable at certain tasks but cannot yet match the brain's most incredible attributes. Our sophisticated organ can interpret and process sensory data on an unparalleled scale; we can stand on the beach in the summer listening to the waves, watching the birds and feeling the heat of the Sun, and compose all of that data into a cohesive setting. We can also learn and adapt from experiences.

Both attributes would be highly advantageous for a computer program to harness. An algorithm has recently been developed that is capable of analysing images from MRI scans to diagnose tumours or anomalies, and developers of artificial neural networks have also taken inspiration from the brain to produce programs that are capable of learning by practice.

These programs still have a long way to go to match the power of the world's greatest supercomputers sat snugly in our heads, but by using the brain as a model, we are growing ever closer to inventing a truly powerful artificial intelligence.

"We may have brain-like computers controlling our smartphones"

Dharmendra S. Modha presents a brain-inspired supercomputer system containing 16 TrueNorth chips

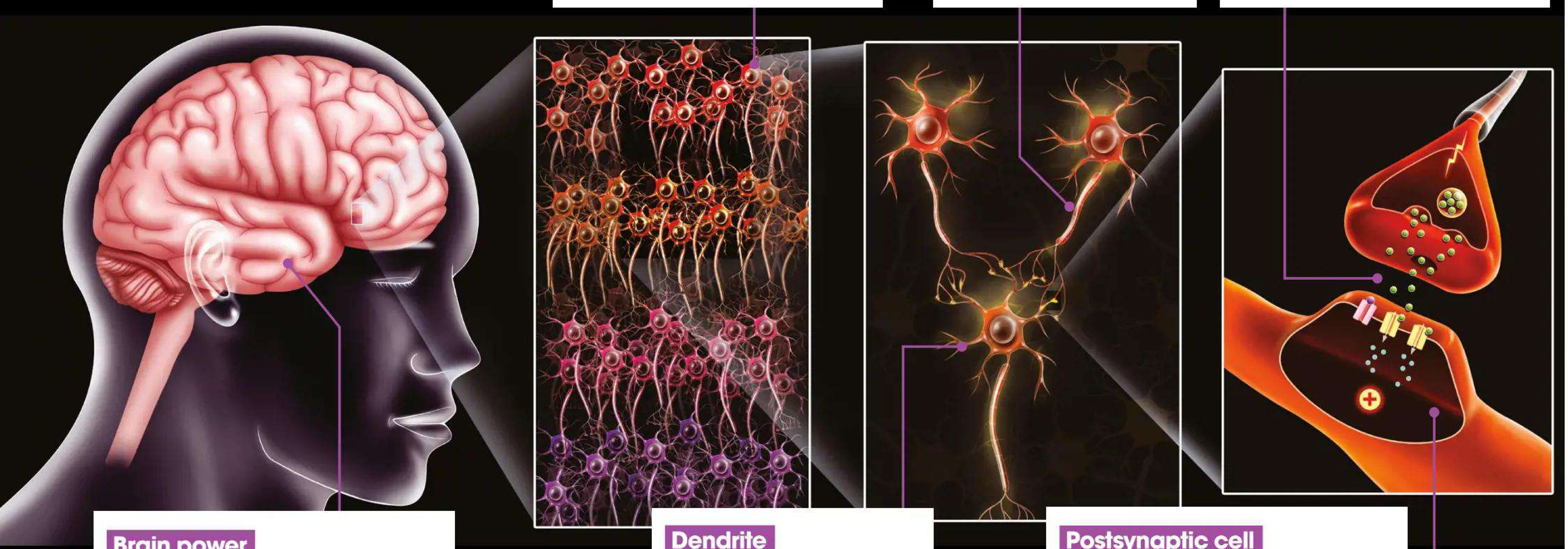


Neurons on a computer chip

Researchers at IBM have turned to the architecture of our brains to develop the TrueNorth computer chip, a brain-inspired processor with 1 million artificial neurons and 256 million artificial synapses. By mimicking the modular and flexible design of the brain, the researchers developed a scaled-down neurosynaptic network with integrated computation and memory, and considerable processing power. The programming language unique to this machine is in the process of being made commercially available, so we may have brain-like computers controlling our smartphones in the near future.

The human brain

Our brains are immense networks of nerve cells that fire electrical signals to exchange information



Robotic animals

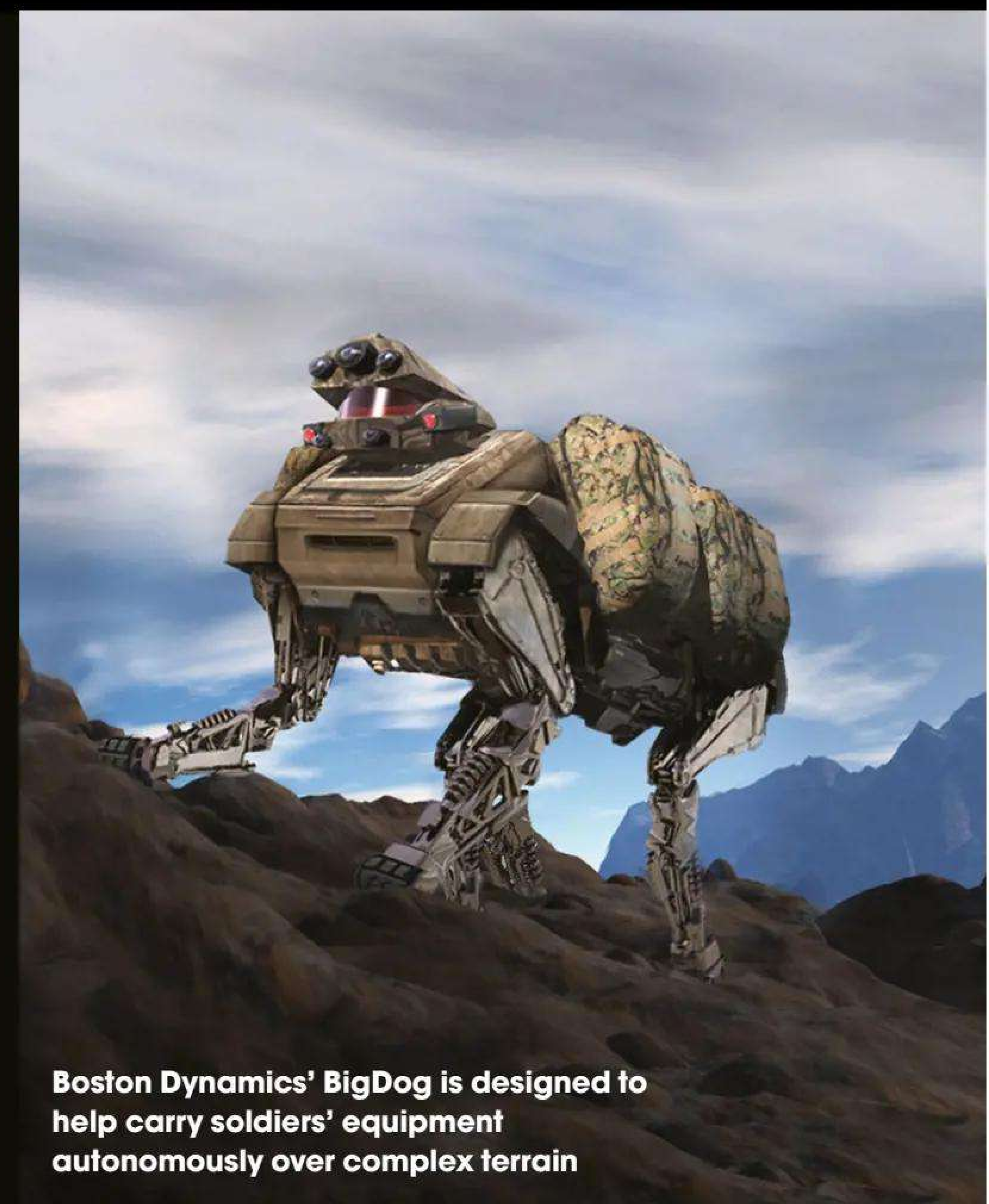
Constructing machines in nature's image

When we imagine a dystopian future, it's almost always filled with robotic assistants. We do not have to stretch our imaginations too far to think of ways that machines could help us: they could play a role in warfare, join rescue teams, or carry our shopping. Today, many scientists are dedicated to constructing machines that can fill these roles – and finding the optimal designs was easy, as nature had already provided the templates.

Animals have adapted to excel in every environment on the planet. Species exist in extreme temperatures, reside on mountaintops, and live in the depths of the ocean. Engineers hope to capture their natural affinity for these locations by copying their specialised features and characteristics. Imitating animal anatomy also allows us to gift robots with admirable abilities, such as incredible speed or the power of flight.

Huge inroads have already been made towards building these machines. A cheetah – the fastest land animal on Earth – achieves great speeds using its flexible spine. The animal's robotic counterpart, developed by Boston Dynamics, flexes its back in a similar way to run at over 45 kilometres per hour. Meanwhile, the giant AlphaDog can carry up to 180 kilograms over large distances, the robotic equivalent of a reliable pack mule.

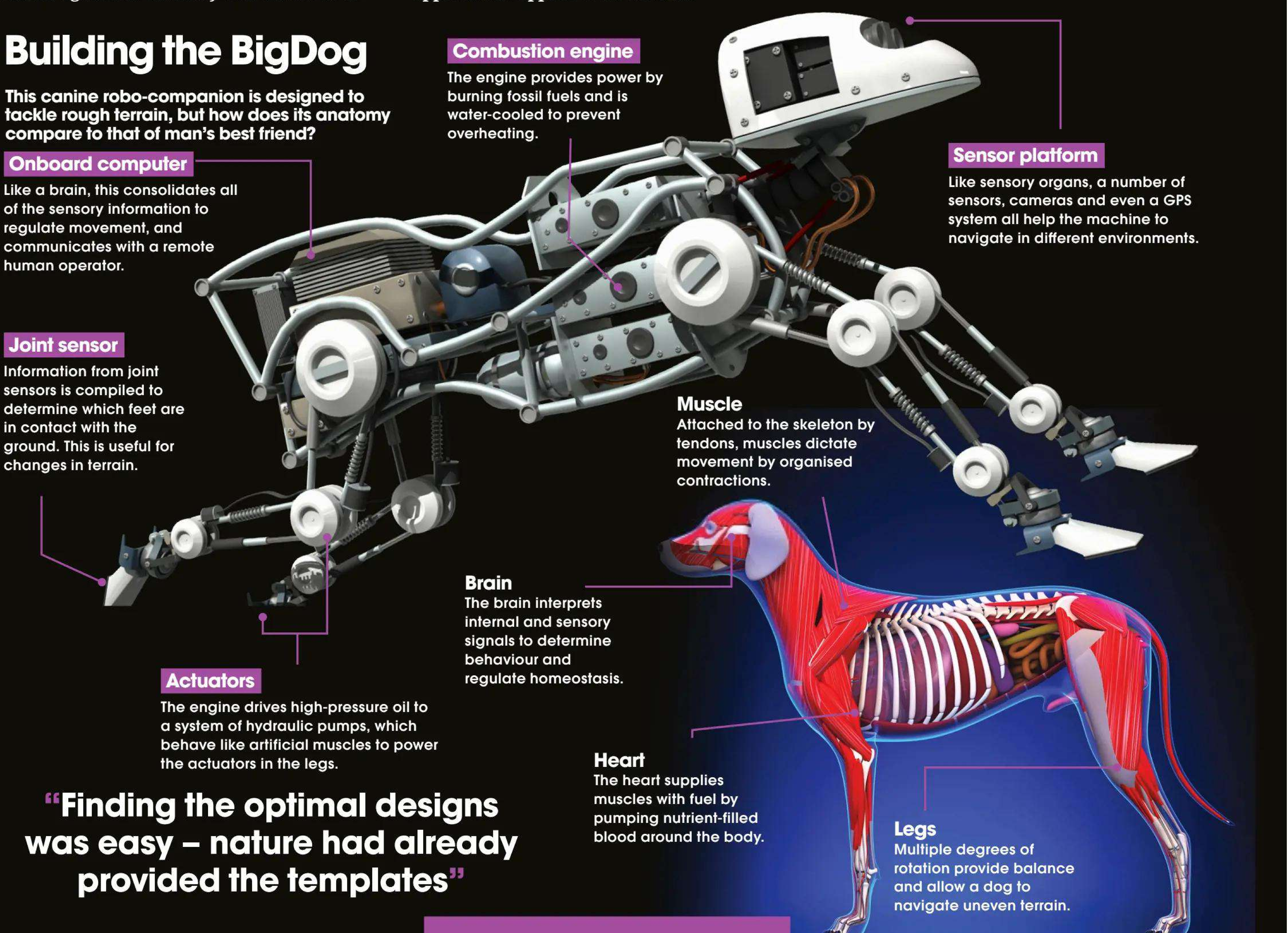
From the tiny RoboBees that could pollinate crops or monitor traffic, to the ape-like android that might even help us to explore Mars, robotic animals of all sizes are really starting to show their potential, and the applications appear to be endless.



Boston Dynamics' BigDog is designed to help carry soldiers' equipment autonomously over complex terrain

Building the BigDog

This canine robo-companion is designed to tackle rough terrain, but how does its anatomy compare to that of man's best friend?



"Finding the optimal designs was easy – nature had already provided the templates"

Tabbot

A species of spider in Morocco has mastered a fancy party trick: cartwheeling. The spider, known locally as 'tabacha', flips up and down sand dunes to escape predators, and this athletic movement formed the blueprint for its robotic cousin, Tabbot. This machine is capable of both walking and somersaulting, and has the potential to traverse deserts both at home on Earth and away on Mars.

RoboClam

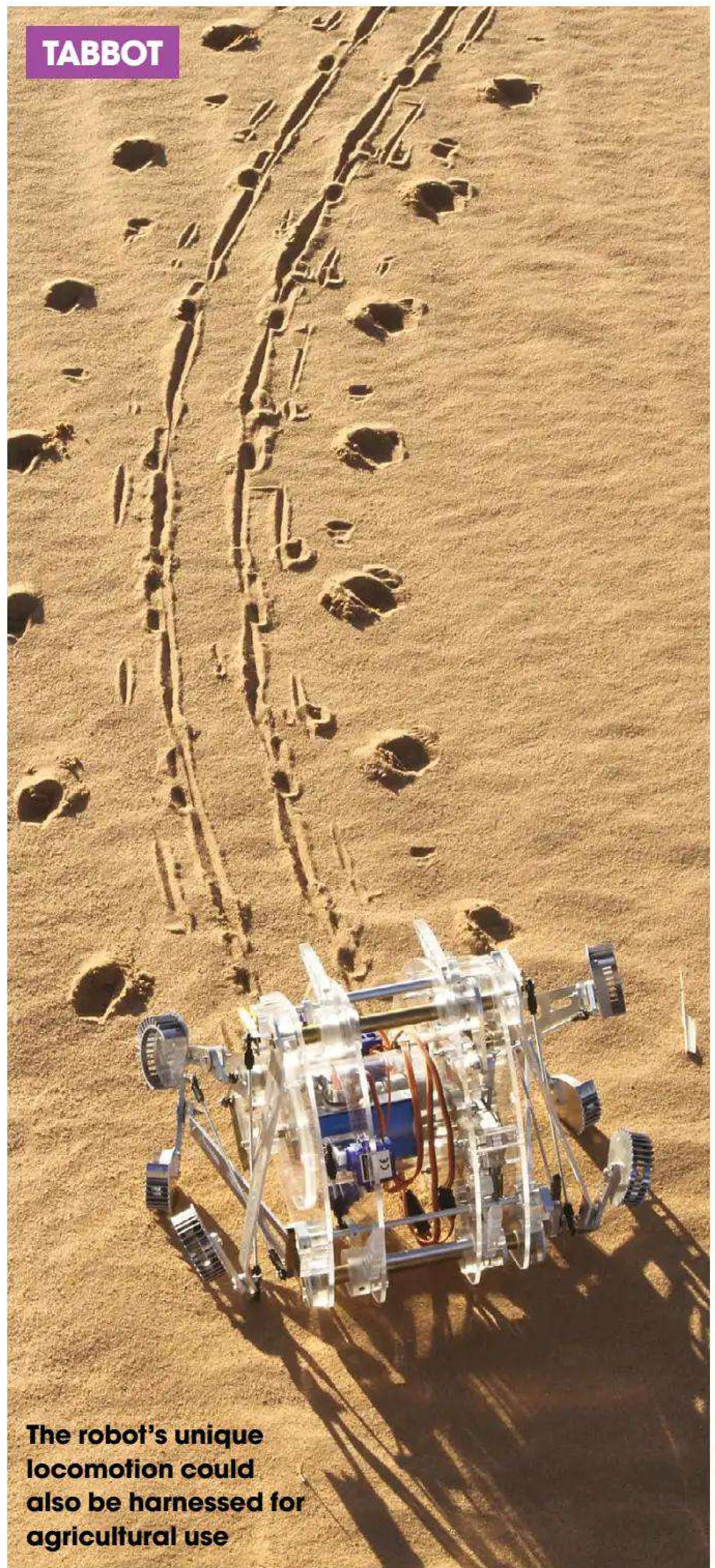
The Atlantic razor clam is a large mollusc capable of digging at incredible speeds that human drills cannot match. It achieves this by forcefully opening and closing the shells on its body to turn surrounding soil into liquid, reducing the resistance faced by the clam as it burrows further into the earth – and all at a low energy cost. Engineers have designed a mechanical device based on these principles that could be used to anchor submarines in the future.

Anti-mine lobsters

Underwater mines pose a serious threat to military submersibles, so the US navy has envisaged deploying robots to scout the sea floor in pursuit of these hidden dangers. In order to develop a machine capable of effectively scouring the depths, they designed a robotic lobster – with the aim of capturing the natural version's efficient, wave-like motion – and attached mine-detecting sensors to the frame.

Rescue cockroaches

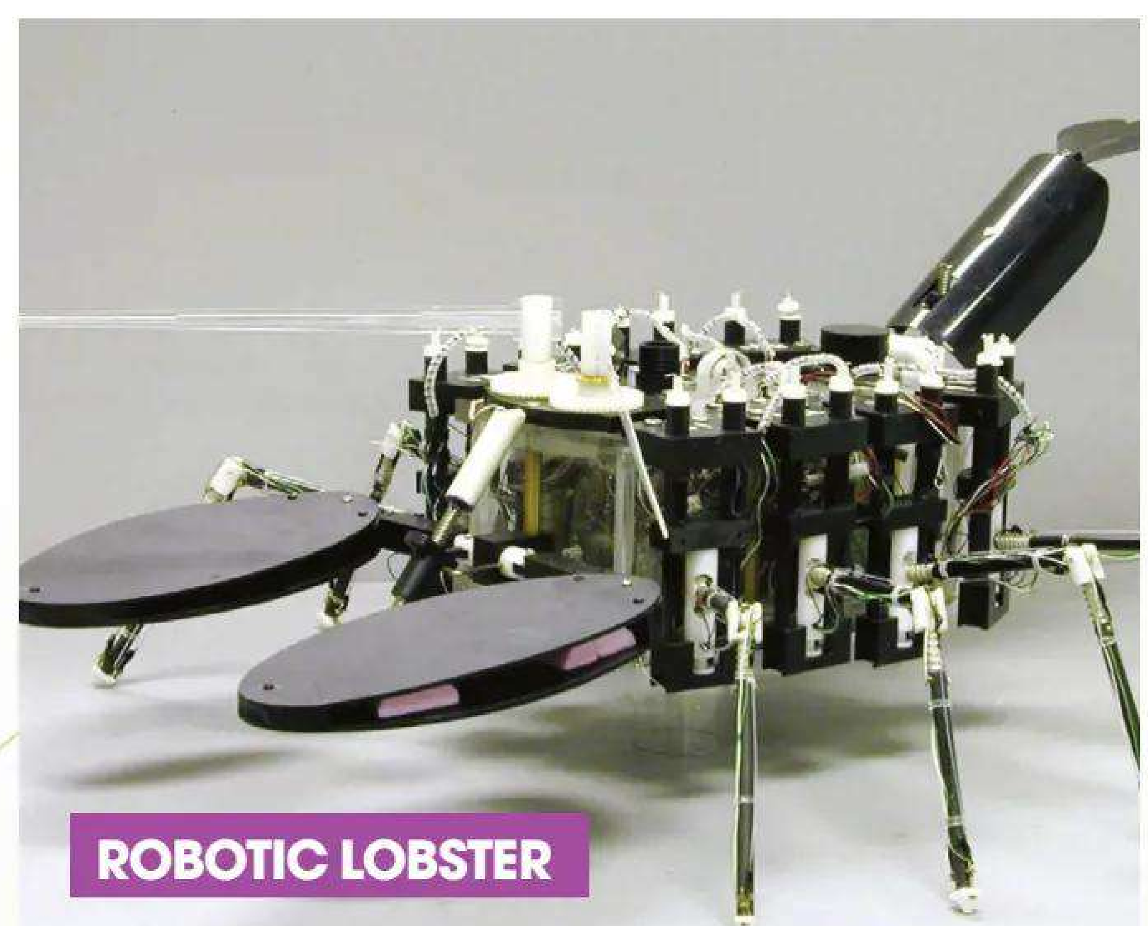
Cockroaches are typically regarded as disgusting nuisances that are notoriously difficult to kill. Researchers found their exoskeletons could withstand a force of 300 times their body weight while still moving, and that they could continue to scuttle rapidly in extremely tight spaces. Their flexible design led to the inception of CRAM – or 'compressible robot with articulated mechanisms' – that has been constructed in the cockroach's image. The capability of this machine to navigate through small gaps has made it an able candidate as a rescue robot, so perhaps in the future the sight of a cockroach will bring a sigh of relief rather than a scream of terror.



The robot's unique locomotion could also be harnessed for agricultural use

Deep submersibles would benefit from a lightweight, reversible anchoring mechanism

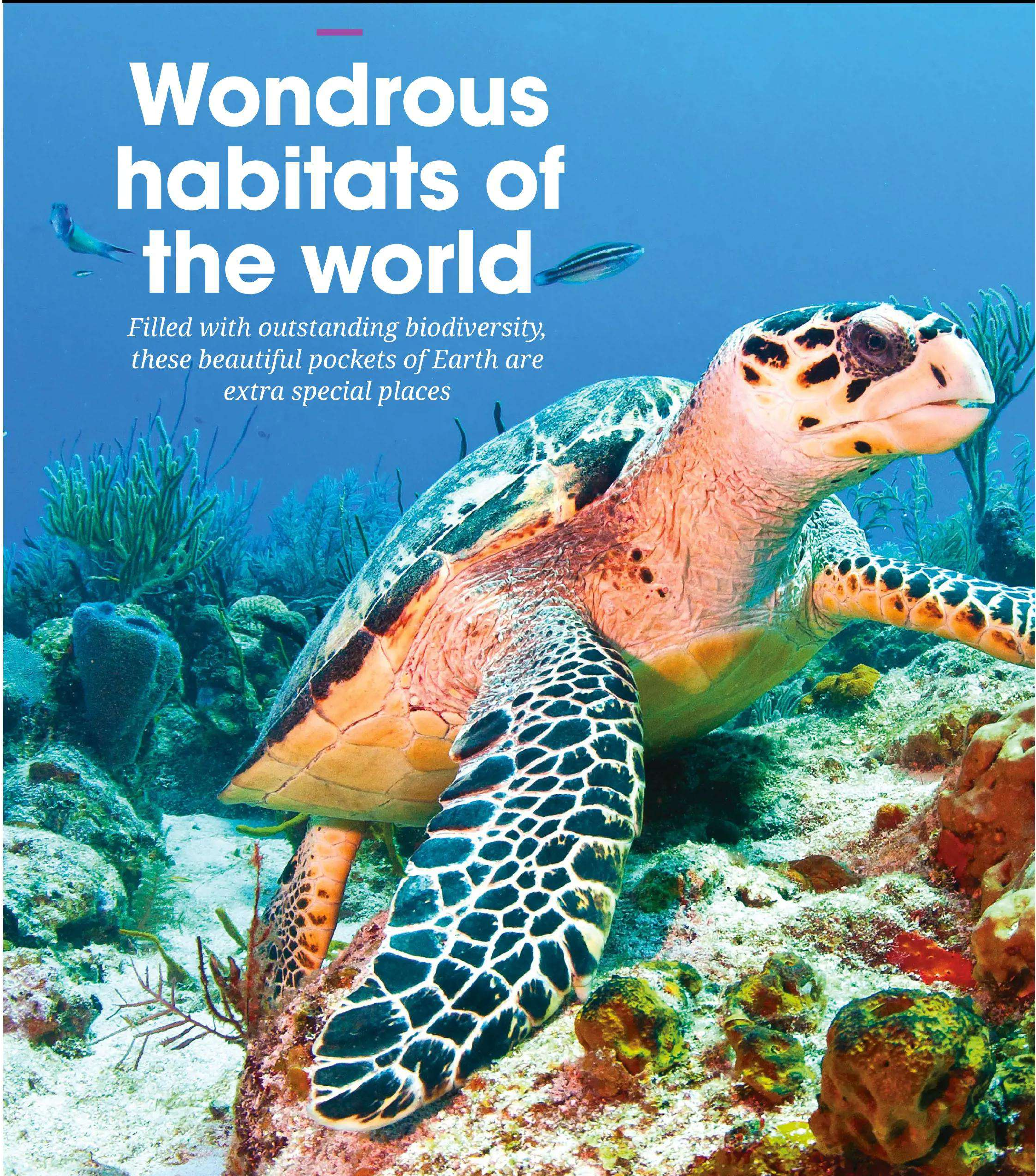
"Perhaps the sight of a cockroach will bring a sigh of relief"



The shape of the robot lobster emulates its natural equivalent's ability to hunt among rocks

ROBOTIC COCKROACH

The CRAM robot can continue crawling even when it is squashed to half its normal size



Wondrous habitats of the world

Filled with outstanding biodiversity, these beautiful pockets of Earth are extra special places

THE WORLD AROUND US

The Coral Triangle

Covering 6 million square kilometres, this the most diverse marine ecosystem in the world

Connecting six nations, this huge 'triangle' of vibrant coral reefs is of incredible importance for ocean and human life alike.

These colossal reefs are teeming with life thanks to the huge amount of space for colonisation, specialisation and evolution and, of course, the promise of food. The sheltered reefs are also essential spawning and nursery grounds for migratory species that then range across the rest of the world's oceans.

Alongside marine life, humans also depend heavily on the Coral Triangle. The reefs are natural barriers that offer protection from storms in the Pacific. They also provide food and essential sources of protein for the islands and support industries such as tuna fisheries and the hugely lucrative tourist industry.

But this crucial ecosystem is under threat. Thanks to overfishing, destructive fishing methods, bycatch and global warming, the reefs and the vast amount of life that they support are in need of conservation like never before.

The critically endangered hawksbill sea turtle nests on beaches throughout the Coral Triangle

6 of 7
species of sea turtle can be found in the Coral Triangle

1.7%
of the Earth's oceans are covered by the Coral Triangle

605
species of coral make up the Coral Triangle. That's 76 per cent of all known coral species!

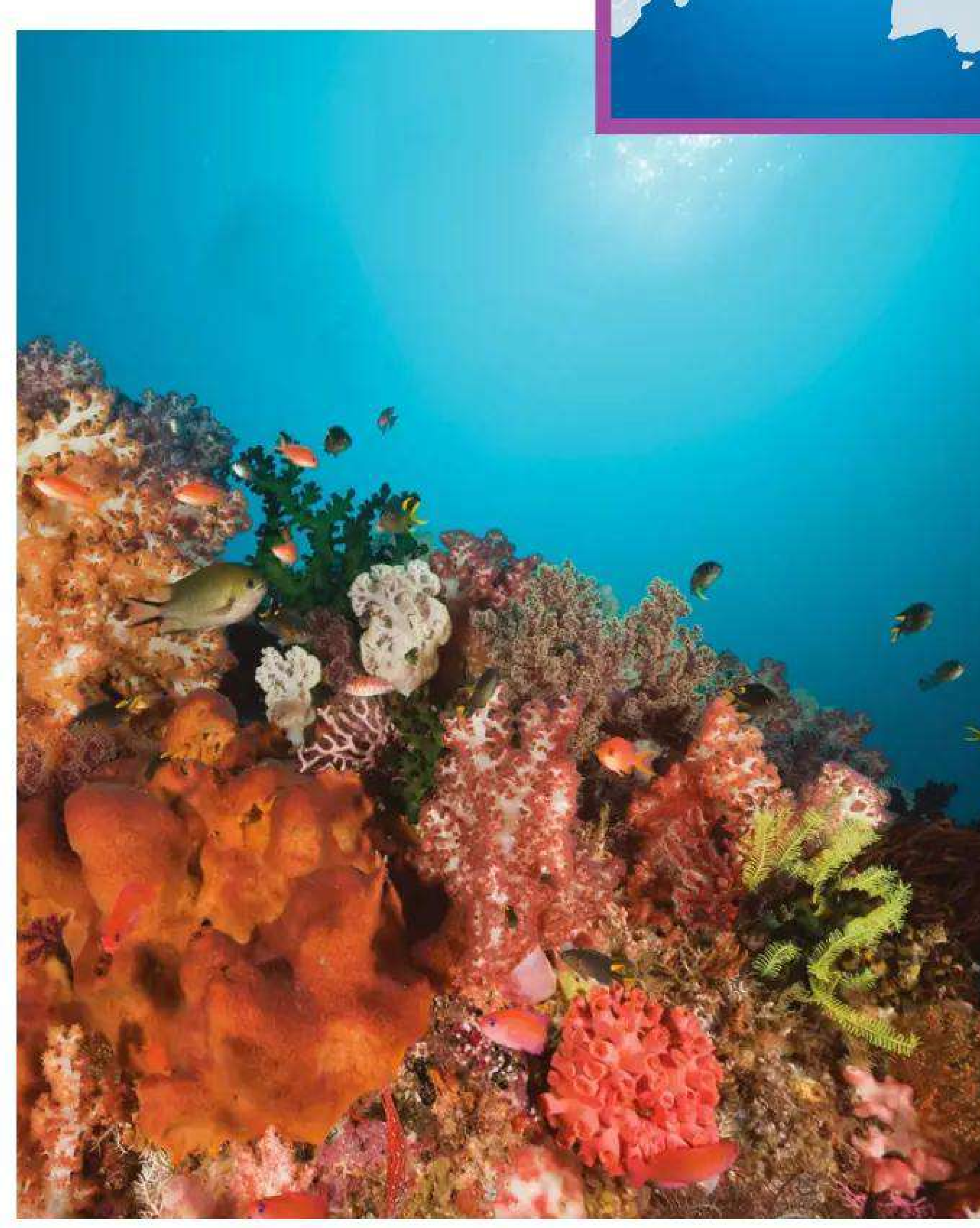
2,228
of the world's 6,000 coral reef fish species live here – that's 37 per cent!

25m
is the average length of a blue whale, the largest animal to have ever lived, which visit the Coral Triangle

Biodiversity hotspots

Defined as an area that supports a high number of unique species, here are the hotspots across the world

Where?



Hard coral secretes a skeleton of calcium carbonate, the stony, reef-building substance that supports entire ecosystems

The largest big cats in the rainforest, jaguars are adept swimmers and will jump into the river to hunt fish, turtles and caiman

The Amazon

This collective biome of river and rainforest is the epicentre of Earth's biodiversity

The Amazon biome spans nine countries and contains almost 400 billion trees of 16,000 different species. It's a complex web of many ecosystems, including rainforests, savannahs, swamps, grasslands and flood plains. Despite covering roughly one per cent of Earth's surface, the Amazon is home to around ten per cent of all known species on the planet. It's incredibly biodiverse; there are more ant species on one tree in the Amazon Rainforest than there are in some countries!

The health of the Amazon is directly linked to the health of our planet. Its trees release around 20 billion tons of water as vapour every day, which brings rain to the continent. The rainforests contain 90-140 billion metric tons of carbon – which would otherwise be emitted into the atmosphere – and help stabilise the world's climate. Deforestation is one of the Amazon's threats, and it could cause the release of some of this carbon, accelerating global warming.

Ocelot

Twice the size of a house cat, these felines hunt rodents, fish and monkeys, taking to the trees as well as the river to hunt.

Amazon river dolphin

There are three species of these freshwater cetaceans, which live throughout the Amazon and Orinoco Rivers.

Emerald tree boa

These strong snakes can grow up to 2m long. Nocturnal predators, they will hunt for mammals, birds and reptiles.

Piranha

The Amazon is home to 20 species of this razor-toothed fish. They feast on fish, crustaceans, worms and carrion.

6.7mn km²
The size of the Amazon biome – that's twice the size of India!

1/5th
of Earth's fresh water is contained in the Amazon Basin

20%
of the world's oxygen is produced in the Amazon rainforest; it's nicknamed the 'lungs of the world'

Over 14 billion cubic metres
of water flows into the Atlantic Ocean every day from the Amazon River

350
different ethnic groups live in the Amazon; more than 60 are still relatively isolated

Scarlet macaw
These brightly-coloured birds have specially adapted beaks for breaking open seeds. They are among the largest parrots in South America.

Sloth
With their super low metabolic rate, the sloths of the Amazon move through the trees at around 36m per day!

Green iguana
Living much of its life in the forest canopy, the green iguana is amongst South America's largest lizards, growing to around 2m long.

Tapir
Found across Central and South America, these able swimmers prefer to live near water. Although not exclusively nocturnal, they tend to forage at night.

Squirrel monkey
Feeding on the rainforest's bounteous fruits, insects and seeds, these monkeys live in groups and vocalise loudly to keep in touch.

> "There are more ant species on one tree in the Amazon Rainforest than there are in some countries"

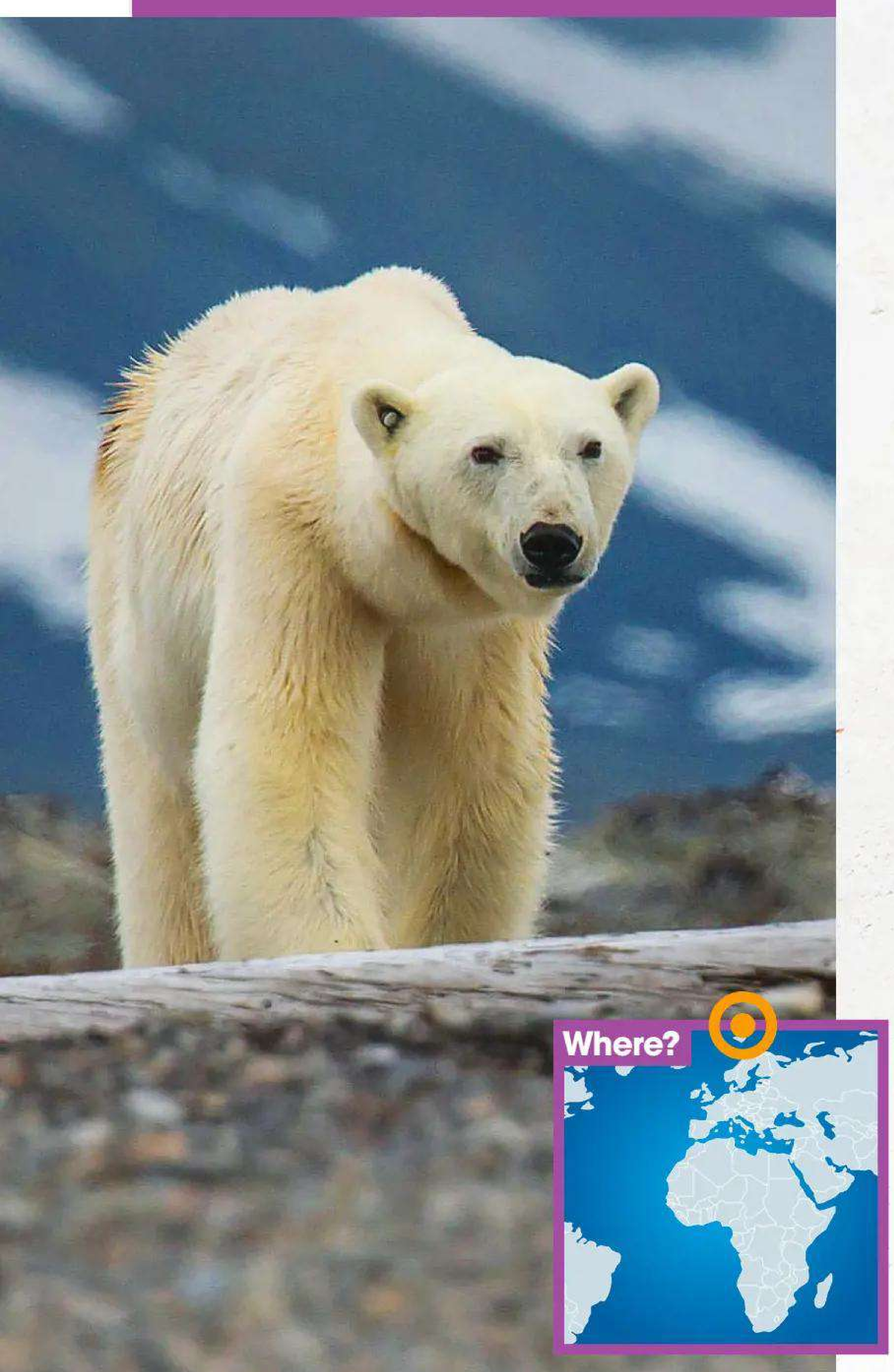
Svalbard Archipelago

Situated between Norway and the Arctic, these islands host some unique wildlife

Thanks to a mix of environmental parameters and different habitats, this group of Arctic islands are home to some incredible animals.

In summer, when the ice and snow retreats, thousands of seabirds flock to the islands to feed on the rich fish pickings. Year-round residents include walruses, narwhal and plenty of seals, and when the sea ice arrives in the winter, polar bears can be seen on the prowl. In the winter snow, arctic hares and foxes sport bright white coats for camouflage.

"Year-round residents include walruses, narwhal and seals. When the sea ice comes, polar bears can be seen on the prowl"



Polar bears are the largest bear species on Earth. They use the sea ice to hunt for blubber-rich seals

Often found basking on the shore, the marine iguana feeds almost exclusively on marine algae

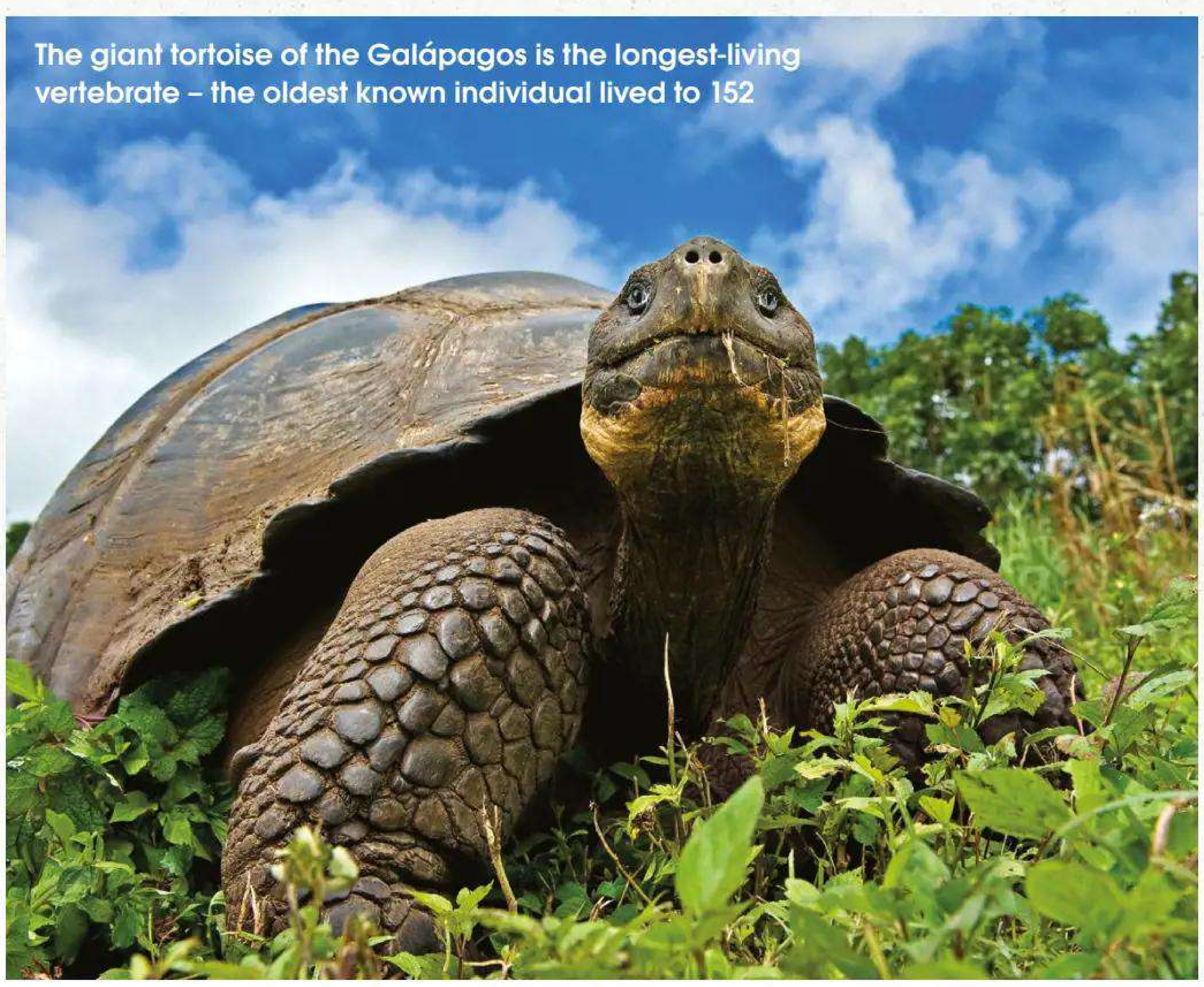
The Galápagos Islands

This archipelago of thirteen major islands is a 'showcase of evolution' both above and below the water

Around 1,000 kilometres into the Pacific Ocean from the Ecuadorian coast, the Galápagos Islands are a hive of endemic species. There are 13 major islands, five of which are inhabited by wildlife found nowhere else in the world.

Thanks to the confluence of three ocean currents, marine animals such as the blue-footed booby, marine iguana, Galápagos fur seal and Galápagos penguin thrive here. On land, plants such as mangroves, cacti and flowering shrubs bloom, while the ancient Galápagos tortoise roams the islands, sharing its home with many finch species made famous by the work of Charles Darwin. The sheer remoteness of these islands has allowed life to flourish independently, with evolution undisturbed by anything from the mainland.

The Sally Lightfoot crab is a total scavenger, feeding on the organic debris of the Galápagos beaches



The giant tortoise of the Galápagos is the longest-living vertebrate – the oldest known individual lived to 152

Madagascar

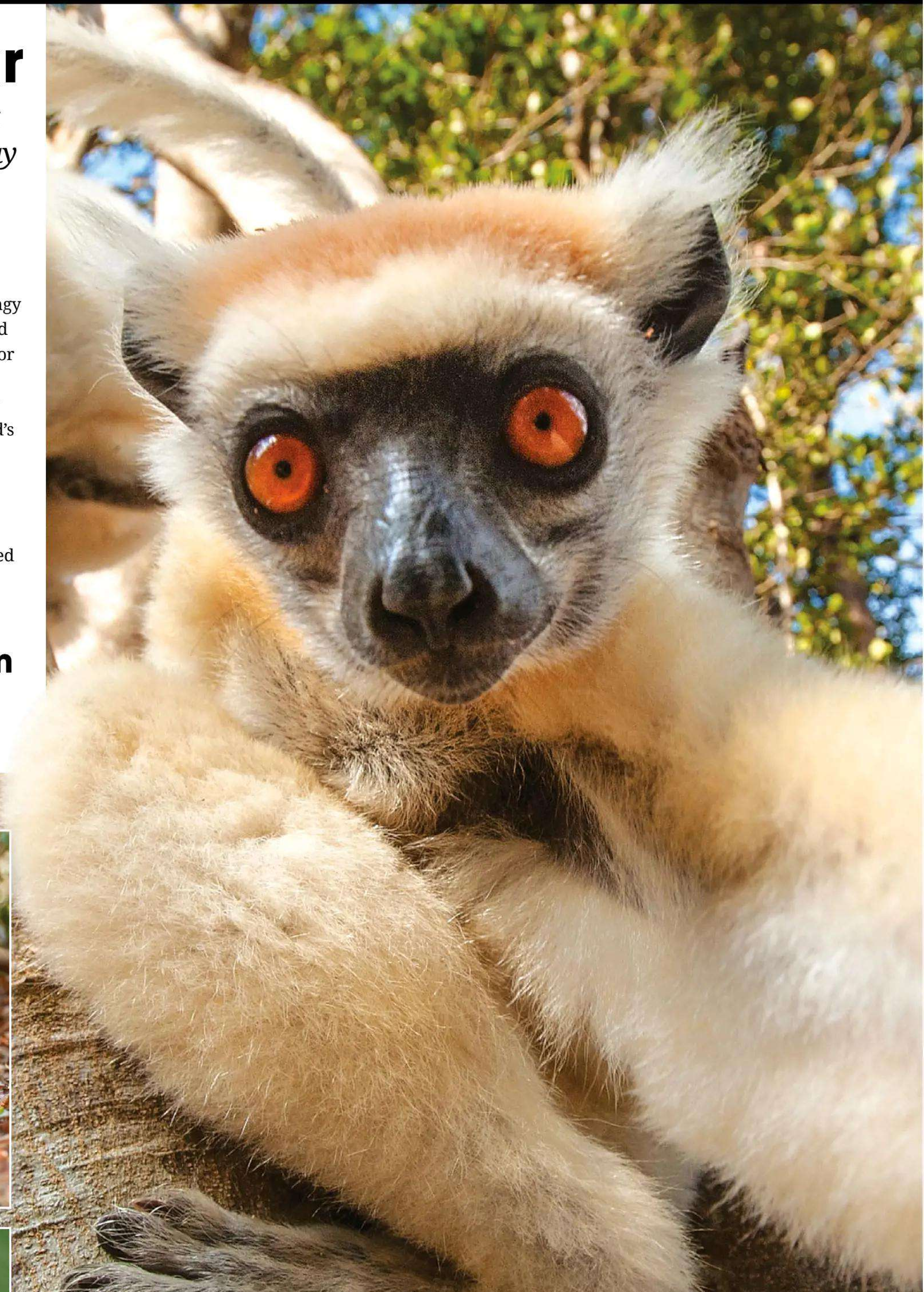
The world's fourth-largest island has an amazing array of unique wildlife

After splitting from the African continent around 165 million years ago, the island of Madagascar developed a diverse array of habitats, including rainforests, savannahs, tsingy (spiny rock formations), coral reefs, marshland and mangrove forests. These provide homes for a great number of amazing species.

There are 11,000 plant species that are only found here. Similarly, 95 per cent of the island's reptiles and 92 per cent of its mammals live nowhere else in the world!

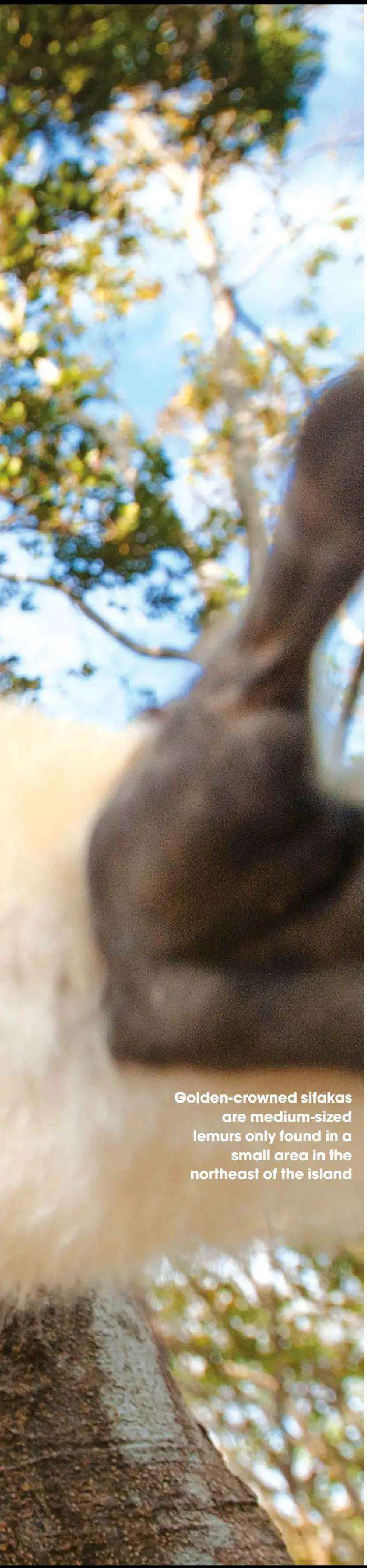
There are many examples of convergent evolution, where animals evolve separately to fill the same niche, so they are totally unrelated but can look and act in similar ways!

"The island of Madagascar split from Africa around 165 million years ago"



The cat-like fossa is Madagascar's top predator, roaming the forests in search of lemurs, its favourite prey

Male panther chameleons from different areas of Madagascar exhibit different (yet equally vibrant) colourings



Golden-crowned sifakas are medium-sized lemurs only found in a small area in the northeast of the island

The Sundarbans mangrove forest

One of the world's largest mangrove systems is a haven for some unique and endangered species

Where?

Threats

This delicate ecosystem is threatened by deforestation, agriculture and the inflow of sewage and industrial pollution.

River delta

The salt-loving mangrove trees thrive on the tidal waterways of the Ganges-Brahmaputra-Meghna River Basin.

Endangered species

These thriving forests are home to the last surviving population of mangrove-dwelling Royal Bengal tigers.

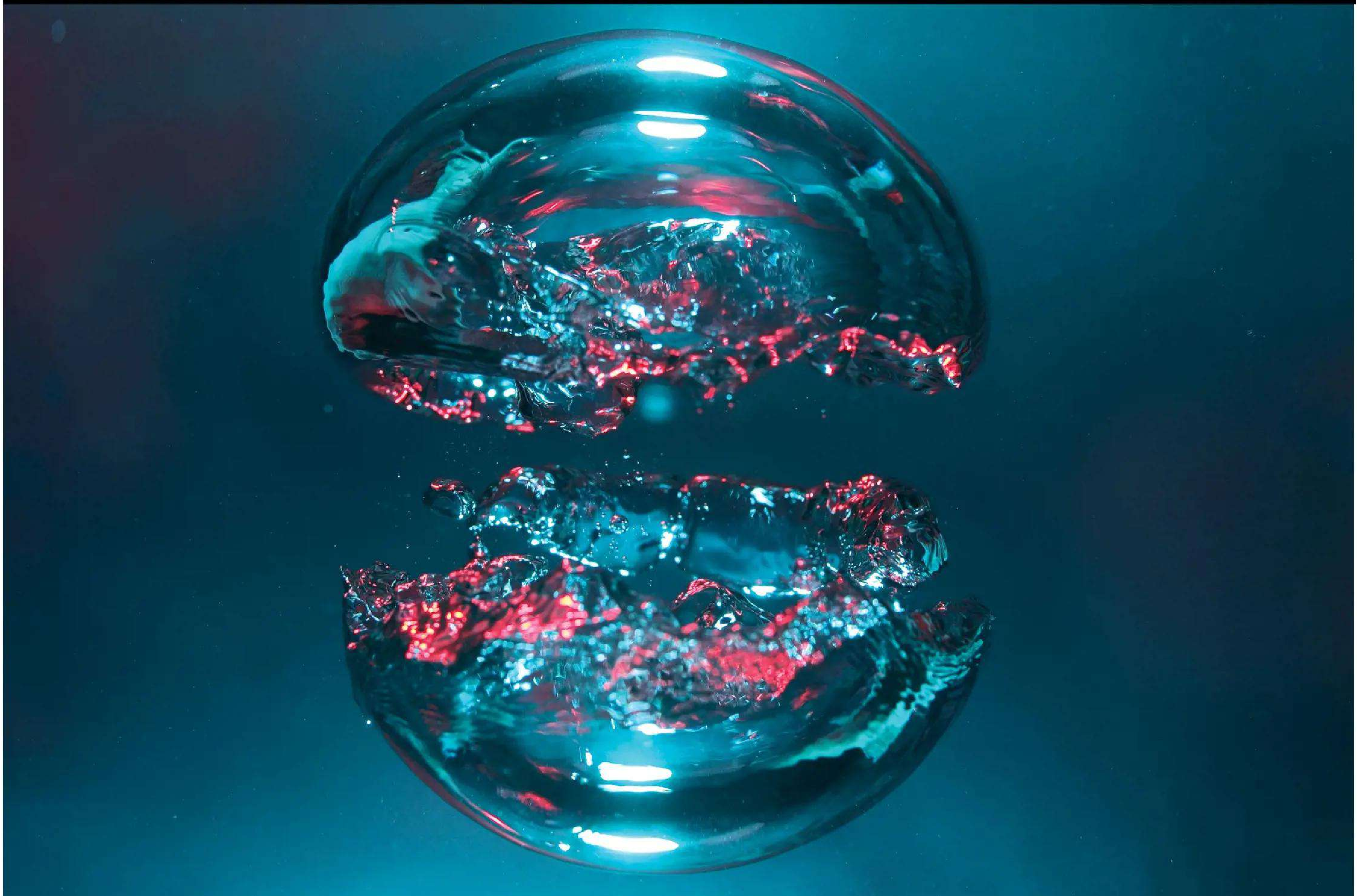
The Sundarbans are home to Earth's largest crocodilian – the saltwater crocodile

Nursery grounds

The deep mangrove roots provide sheltered waterways and protection, making the Sundarbans an ideal nursery ground for many important marine species, such as tiger prawns.

Bay of Bengal

The Sundarbans forest covers a cluster of islands in the Bay of Bengal, spanning 10,000km^2 over India and Bangladesh.



The wonders of water

Discover why this colourless chemical compound is the key to life

A water molecule is composed of just three atoms – one oxygen and two hydrogens. It is smaller than a molecule of carbon dioxide and, based on size, should float around as a gas at room temperature, but instead water molecules manage to hold together as a liquid. This remarkable feat is down to a phenomenon known as hydrogen bonding.

The chemistry of water means that one side of the molecule is positively charged and the other negatively charged. When one molecule comes close to another, these charges attract forming a temporary attachment called a hydrogen bond, which is responsible for many of the amazing properties of water, including its ability to exist as solid, liquid and gas under a range of temperatures and pressures.

The temporary attachments between water molecules enable it to remain liquid over a range of at least 100 degrees Celsius, or even more if the water is salty or under pressure. This means that Earth's rivers and oceans remain stable even as the climate fluctuates. It is because water can freeze, thaw, evaporate and condense within the normal range of temperatures on Earth that we have our weather system. Water molecules can make up to four hydrogen bonds, but in liquid form this almost never happens.

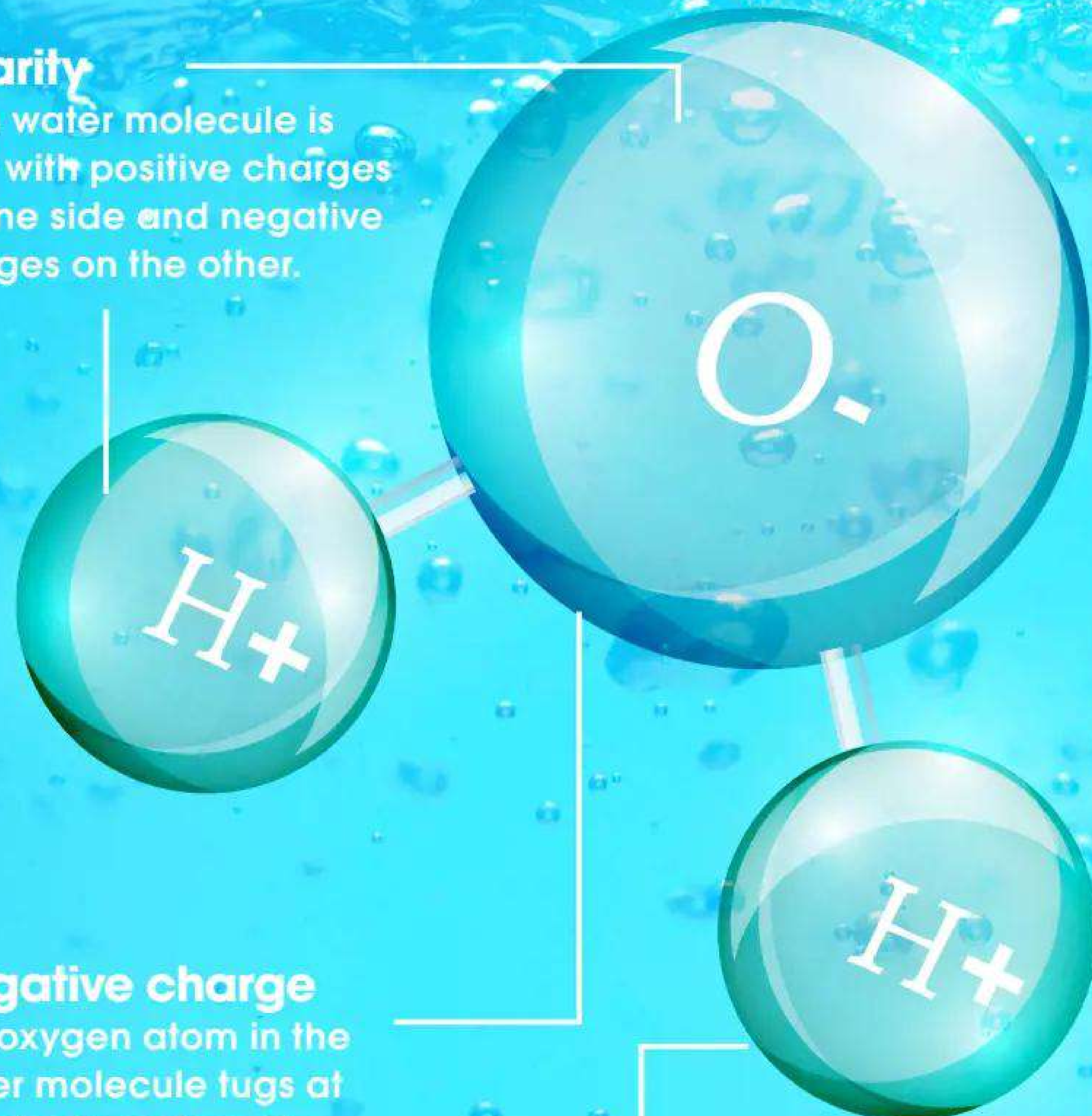
However, as water cools below zero degrees Celsius, the molecules line up to form rigid crystals to maximise these bonds. This structure has lots of gaps, making it less dense than liquid water, causing the ice to float, which is critical to the role of water in maintaining Earth's climate, and in supporting life as we know it. If ice didn't float, lakes would freeze from the bottom up, turning completely solid over winter.

Water is also one of the best solvents in the known universe. The polar molecules can dissolve other charged particles, and even uncharged particles can be pulled into solution under the right conditions. This can alter the planet's geology and bring biological molecules close enough for the chemistry of life to occur. Water is essential to life as we know it and we've harnessed it to achieve incredible things.

What is water?

Water is made up of two key ingredients: hydrogen and oxygen. Each molecule contains one oxygen atom at the centre, bonded to two hydrogen atoms positioned 107.5 degrees apart.

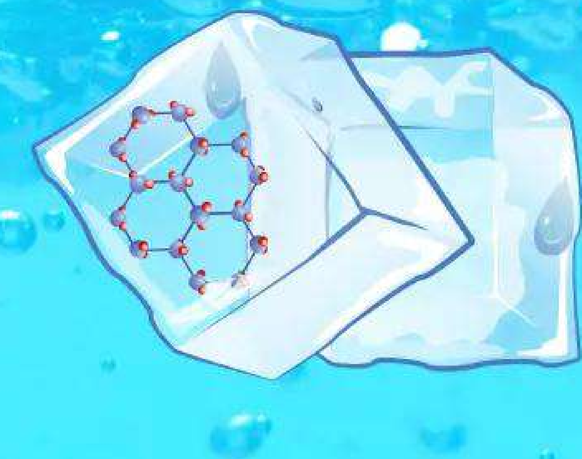
These key pieces of chemistry give water its unique properties. Oxygen is electronegative – it has a tendency to attract negatively charged electrons. This means that it tugs at the electrons belonging to the two hydrogen atoms in the molecule, and because the water molecule is bent it ends up positively charged on one side and negatively charged on the other.



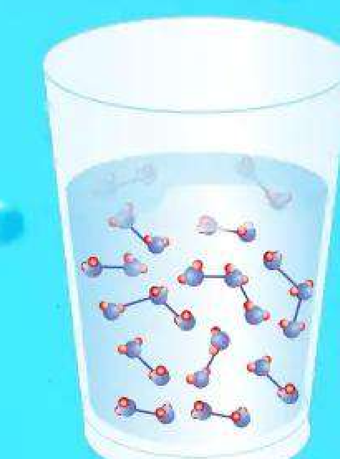
Polarity
Each water molecule is bent with positive charges on one side and negative charges on the other.

Negative charge
The oxygen atom in the water molecule tugs at the electrons from the hydrogen atoms, gaining a slightly negative charge.

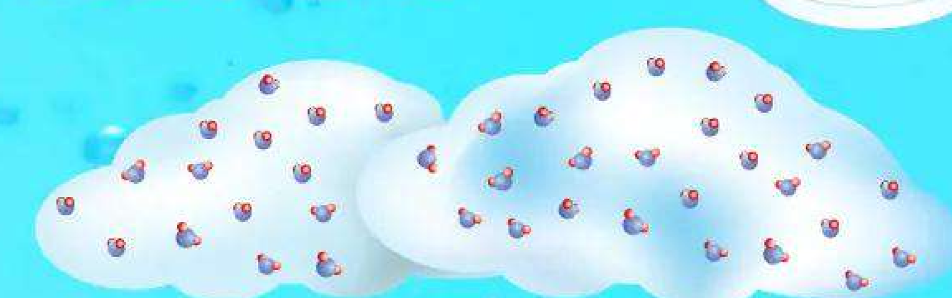
Positive charge
The hydrogen atoms lend their electrons to the oxygen atom, becoming slightly positively charged.



Solid
When water freezes, the molecules line up to form an orderly crystal structure. The bends in the molecules prevent them packing too closely, leaving lots of tiny gaps.



Liquid
Strangely, in liquid form, water molecules are able to get closer. The positive and negative charges pull the molecules together, making water denser than ice.

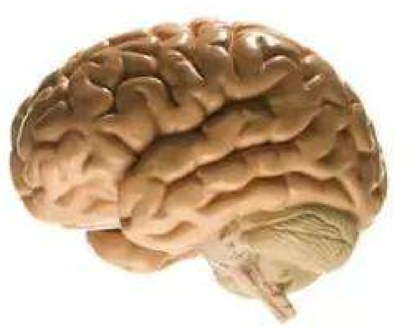


Gas
If water molecules are given enough energy they can break away from the pull of their neighbours, moving apart and forming a gas known as water vapour.

Water in the body

More than half of your body is water and everything that happens inside you depends on it. Water is the solvent that enables vital biochemical processes to occur. It dissolves the chemical building blocks of life, preparing them for transport and construction.

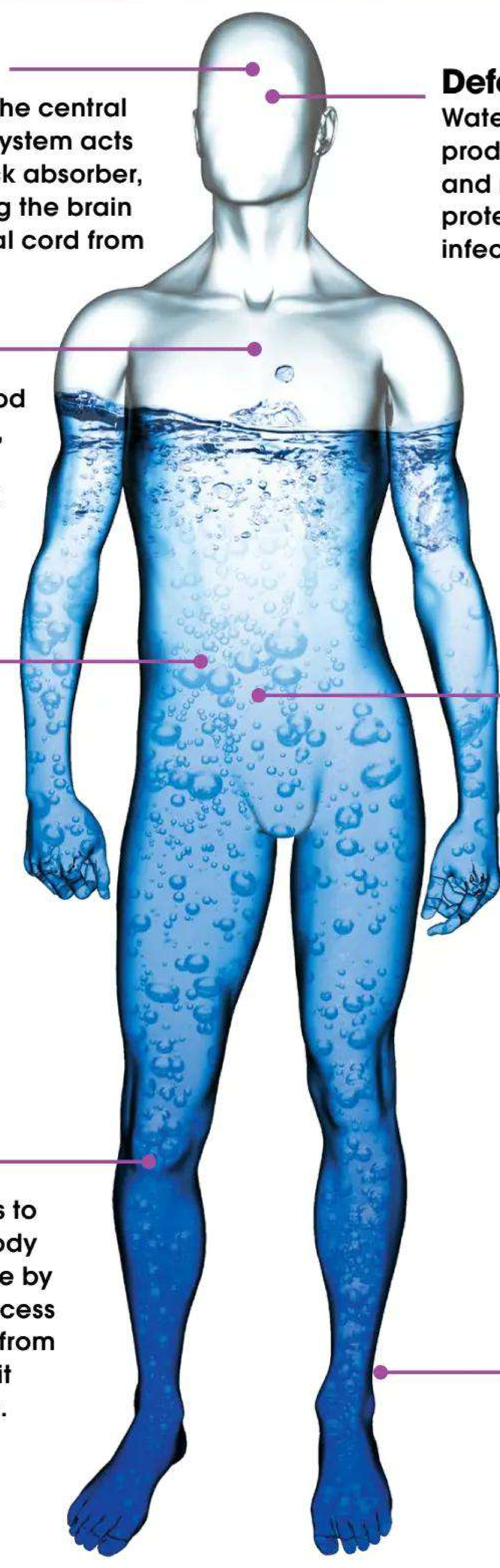
Without water, the body rapidly starts to malfunction. The effects are noticeable when just two per cent of total body water is lost, but if the amount drops to over 15 per cent, it can be fatal. With less water in the blood, the heart must work harder. Rising levels of salt cause muscles to spasm and water loss from the brain leads headaches, dizziness and confusion. Eventually, multiple organs start to fail.



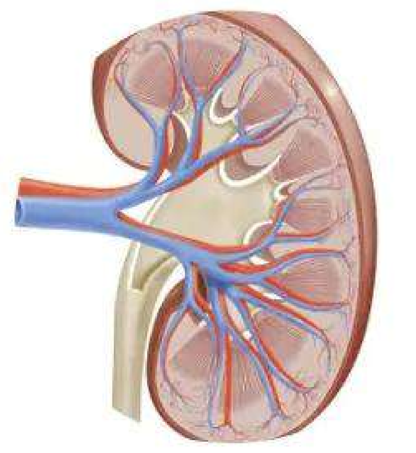
Brain
Water in the central nervous system acts as a shock absorber, protecting the brain and spinal cord from damage.

Defence
Water is used to produce tears, saliva and mucus, helping to protect our bodies from infections and irritants.

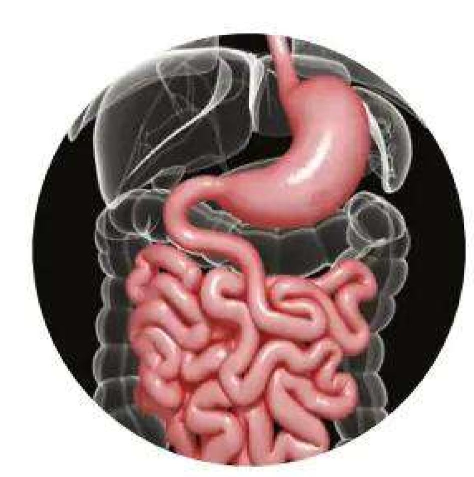
Blood
Water in the blood acts as a carrier, transporting red and white blood cells, gases and nutrients around the body.



70%
or more of our brain is water



Kidneys
The kidneys use water to wash away waste products, like excess salt and urea.



Digestive system
Water helps to keep food moving through the digestive system, allowing enzymes to access the nutrients inside.

50%
of our blood is water

Skin
Water helps to regulate body temperature by carrying excess heat away from the skin as it evaporates.

2 LITRES PER HOUR
how much water we can lose during intense exercise

Bones
Bones might look dry, but they are around 25 per cent water by weight, helping nutrients to reach the living cells inside.

400-2,000ml
how much urine we produce each day

How we use water

Our lives have been tied to water since the very beginning

It is no coincidence that cities like London, Paris and New York straddle vast rivers. We depend on water for our survival. For millions of years, our ancestors chased after this precious resource, but a few thousand years ago modern humans started to tame it.

The major technological advancement that changed our relationship with water was agriculture. From around 10,000 BCE humans gradually stopped hunting and gathering, and began cultivating crops and keeping livestock. Pioneering farmers in Ancient Egypt and Mesopotamia dug drains and channels to regulate water flow to their fields, and in Ancient China, the Yangtze river basin was adapted to create paddy fields for growing rice.

This infrastructure paved the way for the expansion of local settlements, and as water communities worked together to handle periods of flood and drought, they transformed arid landscapes into productive oases. The ability to develop the land and to grow food to meet or even exceed demand, has been one of the keystones in the development of the modern world. To this day, agriculture is still the single largest use of freshwater on the planet, accounting for almost three quarters of the water we use each day.

Water is also used for transport and exploration, and carried our ancestors and their belongings to all corners of the Earth. This facilitated a global trade of objects and ideas, paving the way for the development of new technologies, like the water wheel. First used to move water from one place to another, water wheels were later harnessed to perform work. The Ancient Greeks were some of the first to capture their power to grind grain more than 2,000 years ago. By 1880, this technology had been adapted to produce electricity to power lights and today we have transformed the old-fashioned water wheel into modern hydroelectric turbines.

The invention of the water wheel led to the development of pumps and valves, and when the first reliable steam engine was built in 1775, it drove the Industrial Revolution and changed the world forever. Today, around 20 per cent of the water used every day on this planet is consumed by industry, playing a vital role in the generation of power and in the manufacture of goods. Only a small amount of water is used in the home – much of this for cleaning and sanitation – and amazingly, just fractions of a per cent of our daily freshwater is actually used for drinking.

Clothes
Growing the cotton for new clothes uses lots of water – 2,700 litres (713 gallons) for just one shirt.

x1,350

We only drink 1% of the water we use every day

Books
It takes more than ten litres (2.6 gallons) of water to make a single sheet of paper.

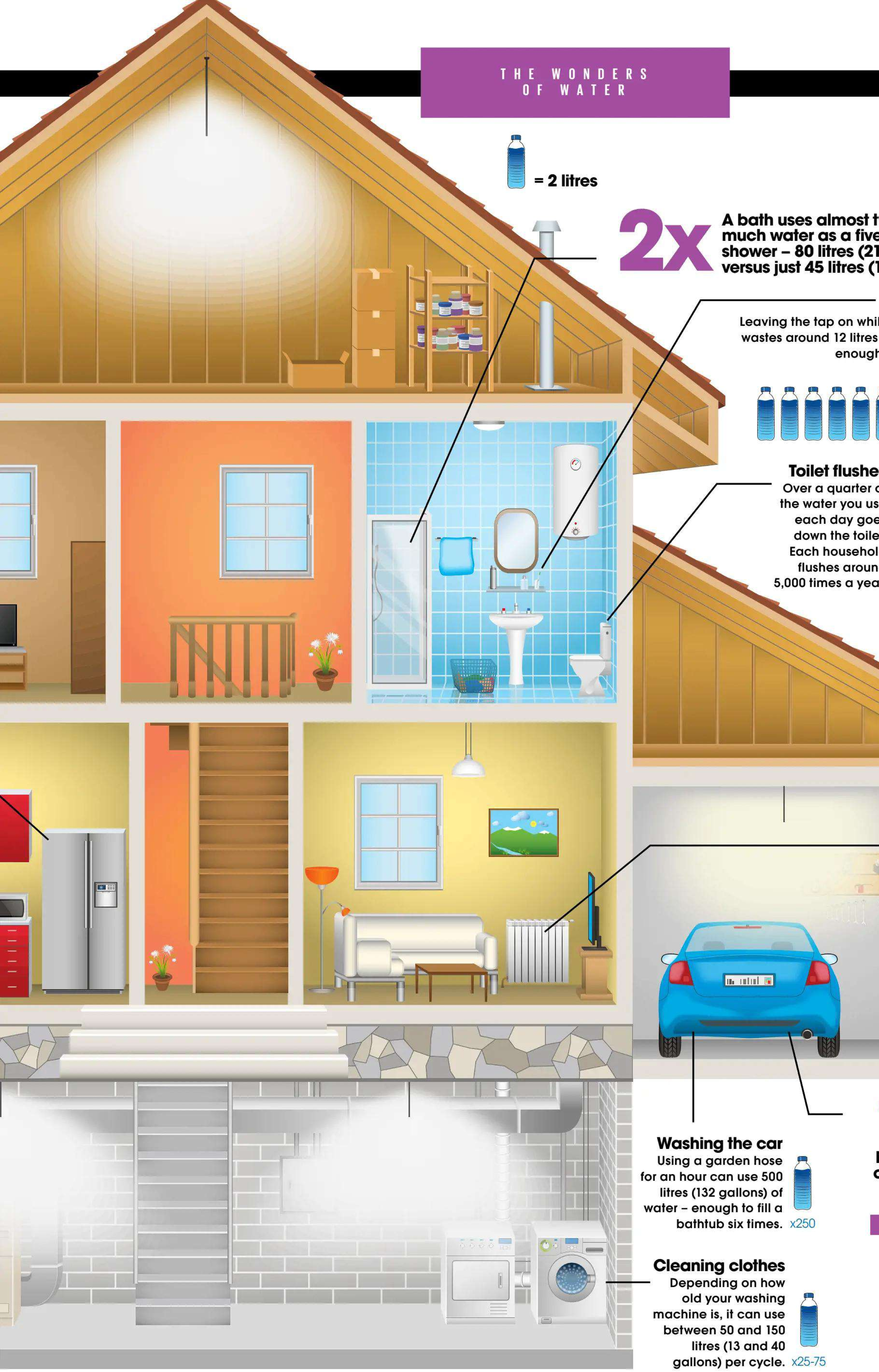
Electricity
Making the electricity needed to watch nine episodes of your favourite television uses nearly two litres (0.5 gallons) of water.

1,000 litres
It takes around 264 gallons of water to produce less than one litre (0.26 gallons) of milk

5,000 litres (1,321 gallons)
How much water a dripping tap wastes in three months

60sec
The time it takes to use the same amount of water as an entire dishwasher cycle if you wash up under a running tap

1.5mm
A tiny 0.06-inch hole in a pipe can leak more than 100,000 litres (26,420 gallons) of water in a year



= 2 litres

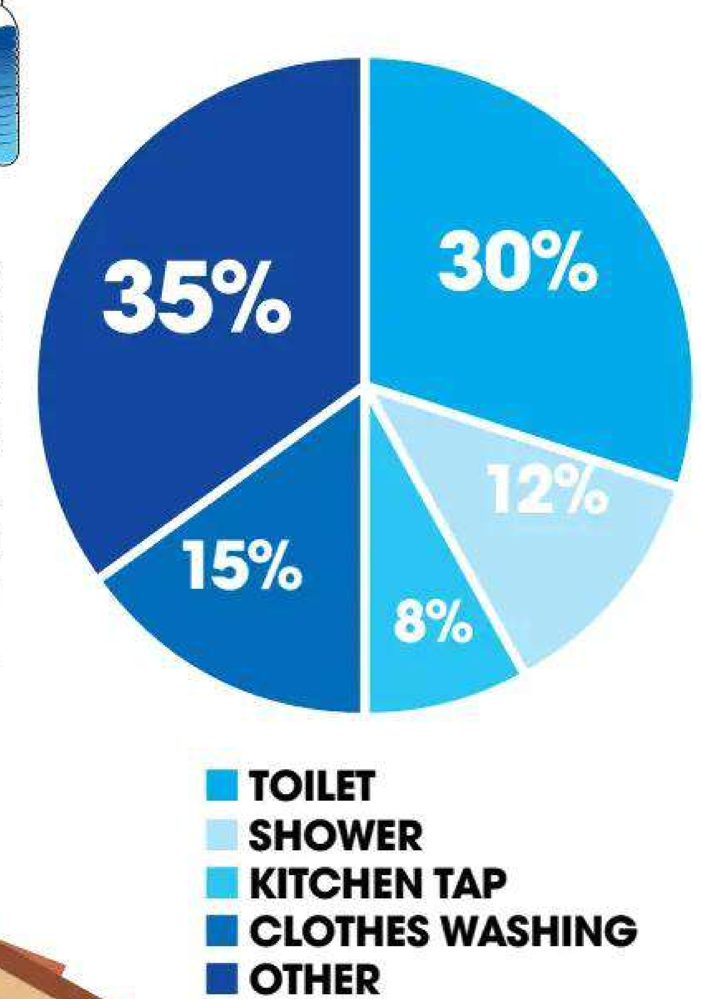
2x A bath uses almost twice as much water as a five-minute shower – 80 litres (21 gallons) versus just 45 litres (12 gallons)

Tooth brushing

Leaving the tap on while cleaning your teeth wastes around 12 litres (3.2 gallons) of water, enough to fill a large bucket.

Toilet flushes

Over a quarter of the water you use each day goes down the toilet. Each household flushes around 5,000 times a year.



Radiator

The average radiator contains around five litres (1.3 gallons) of water.

Washing the car

Using a garden hose for an hour can use 500 litres (132 gallons) of water – enough to fill a bathtub six times. x250

180,000 litres

It takes over 47,551 gallons of water to make a new car

Cleaning clothes

Depending on how old your washing machine is, it can use between 50 and 150 litres (13 and 40 gallons) per cycle. x25-75

150 litres

The average amount of water each person in the UK uses per day

The water cycle

The water that we see on Earth today is the same water that was here at the time of the dinosaurs. It is constantly recycled in a circular system powered by the Sun. During the day, water on the surface of the Earth is heated. As the molecules gain energy, they start to break free from the hydrogen bonds that hold them close to their neighbours and they become water vapour.

The vapour is carried up into the atmosphere by rising currents and as it climbs higher, it begins to cool. The vapour starts to condense to form water droplets, which then gather together in vast clouds. Air currents high in the atmosphere transport the clouds across the globe, blowing the droplets far from their origin, but as more vapour condenses they become too heavy to remain suspended in the sky. Depending on the temperature, the water eventually falls back to the ground as rain, hail or snow.

This water can fall directly into a river or ocean, or it can take a more convoluted path back to the beginning of the water cycle. Much of the water that hits the ground runs straight off and into the nearest body of water.

Some of the water seeps into the soil and is sucked up by thirsty plants, while some flows into underground reservoirs. Some water freezes at the top of slow-moving glaciers, but eventually, it all makes its way back to the start and the cycle begins again.

1 Evaporation and transpiration

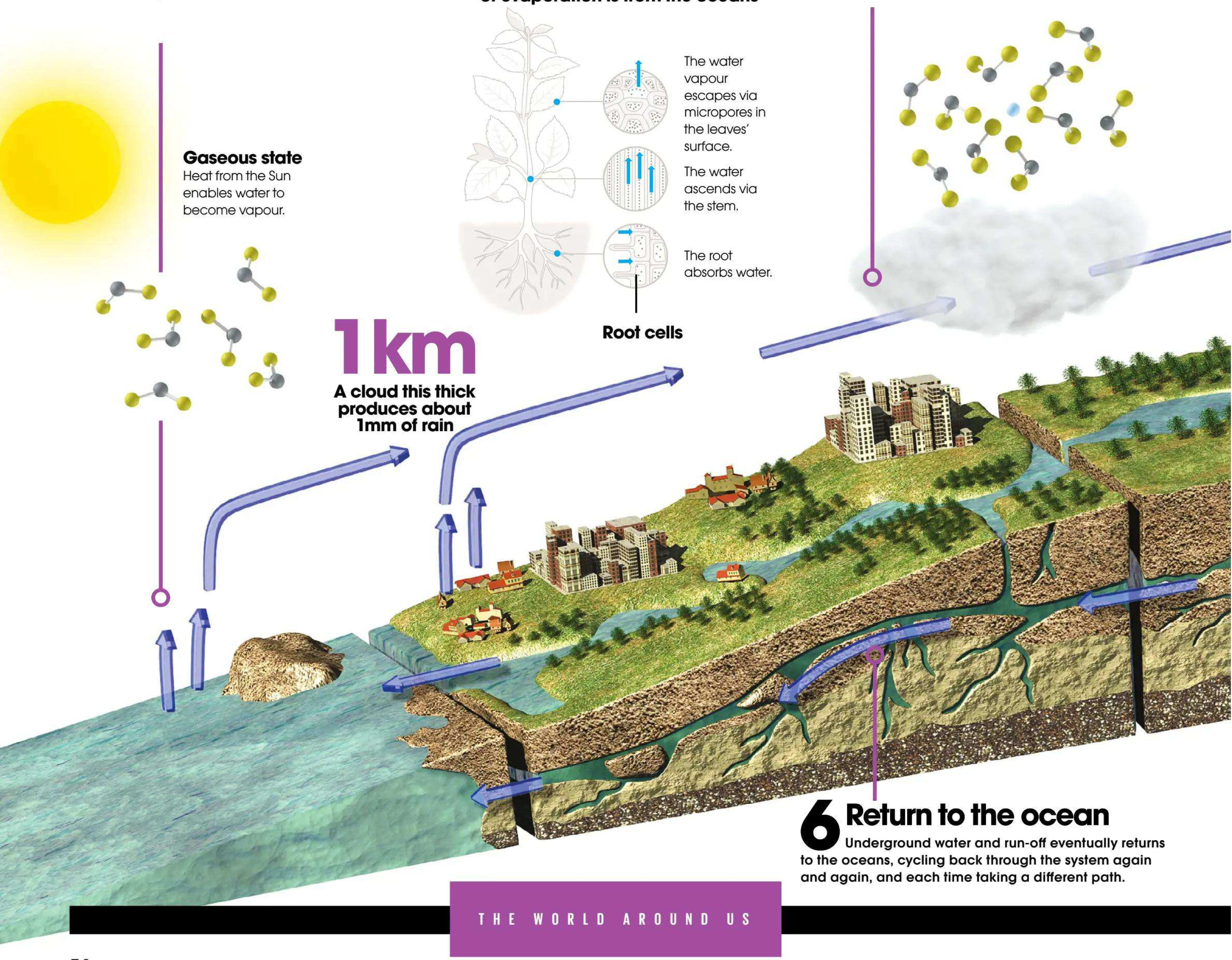
The Sun warms water in the oceans and on the Earth's surface, causing it to evaporate. Water is also lost from the leaves of plants and from the skin of animals.

80%

of evaporation is from the oceans

2 Condensation

As water vapour climbs high in the atmosphere, the temperature drops and it condenses around particles of dust in the air, forming clouds of tiny water droplets.



6 Return to the ocean

Underground water and run-off eventually returns to the oceans, cycling back through the system again and again, and each time taking a different path.

Water availability Cubic feet per capita/year

- Less than 1,700m³ (60,000ft³)
- 1,700-5,000m³ (60,000-175,000ft³)
- More than 5,000m³ (175,000ft³)

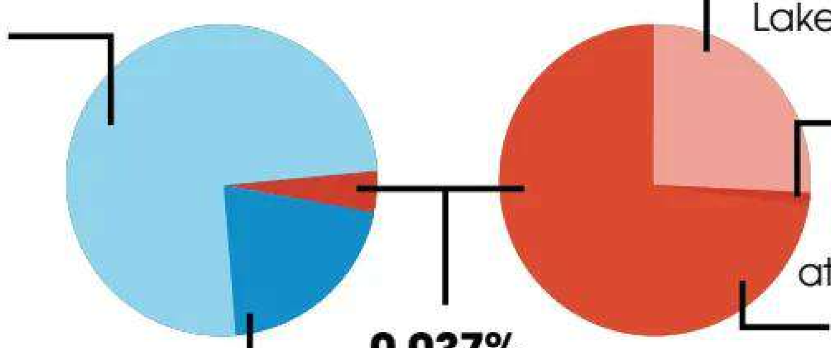
Almost 80% of the world's population has access to drinking water

Where it is found

3% Freshwater **97%** Salt water

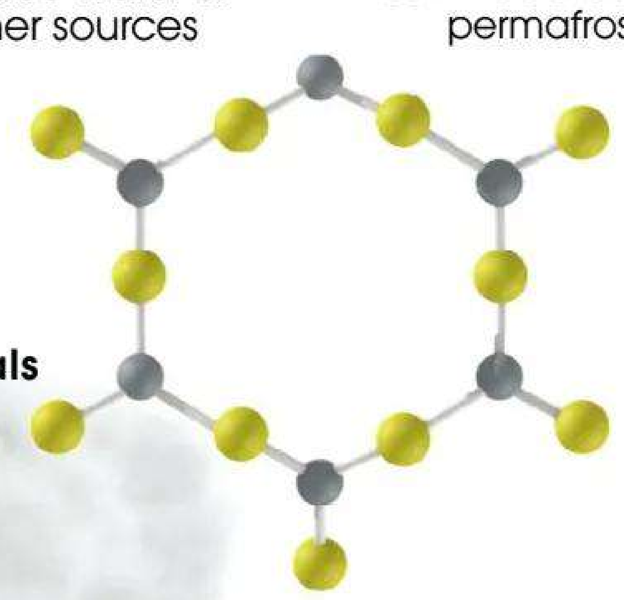
A small percentage is freshwater; most of it is salt water.

Freshwater distribution



Solid state

Water molecules form orderly crystals in ice and snow.

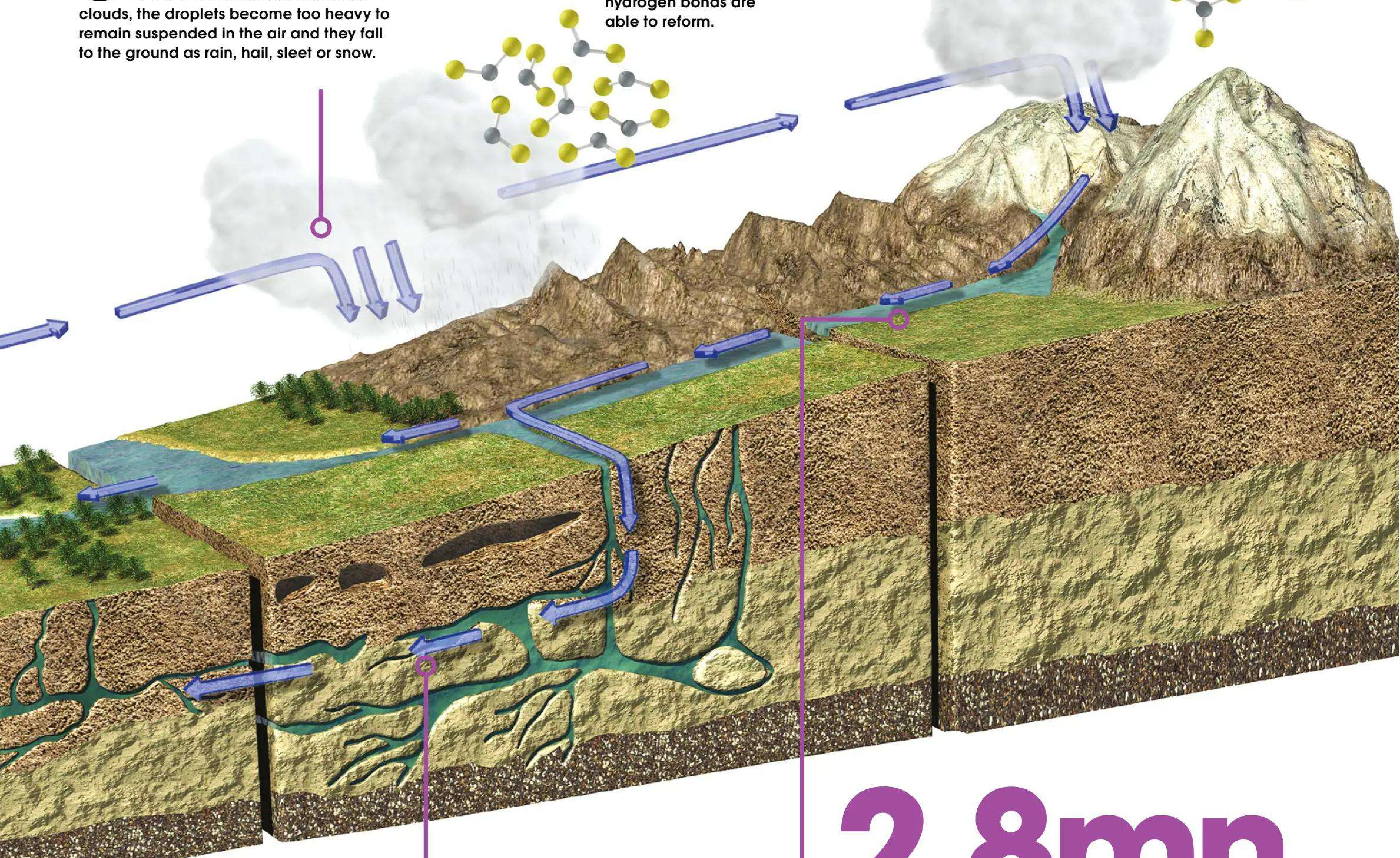


3 Precipitation

As more water condenses in the clouds, the droplets become too heavy to remain suspended in the air and they fall to the ground as rain, hail, sleet or snow.

Liquid state

As the vapour cools, hydrogen bonds are able to reform.



2.8mn

litres of water flow over Niagara Falls each second

5 Underground circulation

Some water travels underground, gathering in reservoirs, flowing in buried streams, dripping through pores and channels in the rocks, or creeping along as glacial ice.

500

quadrillion litres of rain falls every year

4 Run-off

Much of the water that falls to the Earth as rain runs straight off the ground and back into lakes, streams, rivers and oceans. This is more common in environments that have frequent rain.

Water in space

Why has the search for life become the search for water?

Life and water are inextricably linked. Life as we know it needs a solvent in order to exist – a liquid carrier that can dissolve biological molecules, allowing them to come into contact and therefore enabling the chemistry of life to occur. Water is the only molecule known to be able to perform this function.

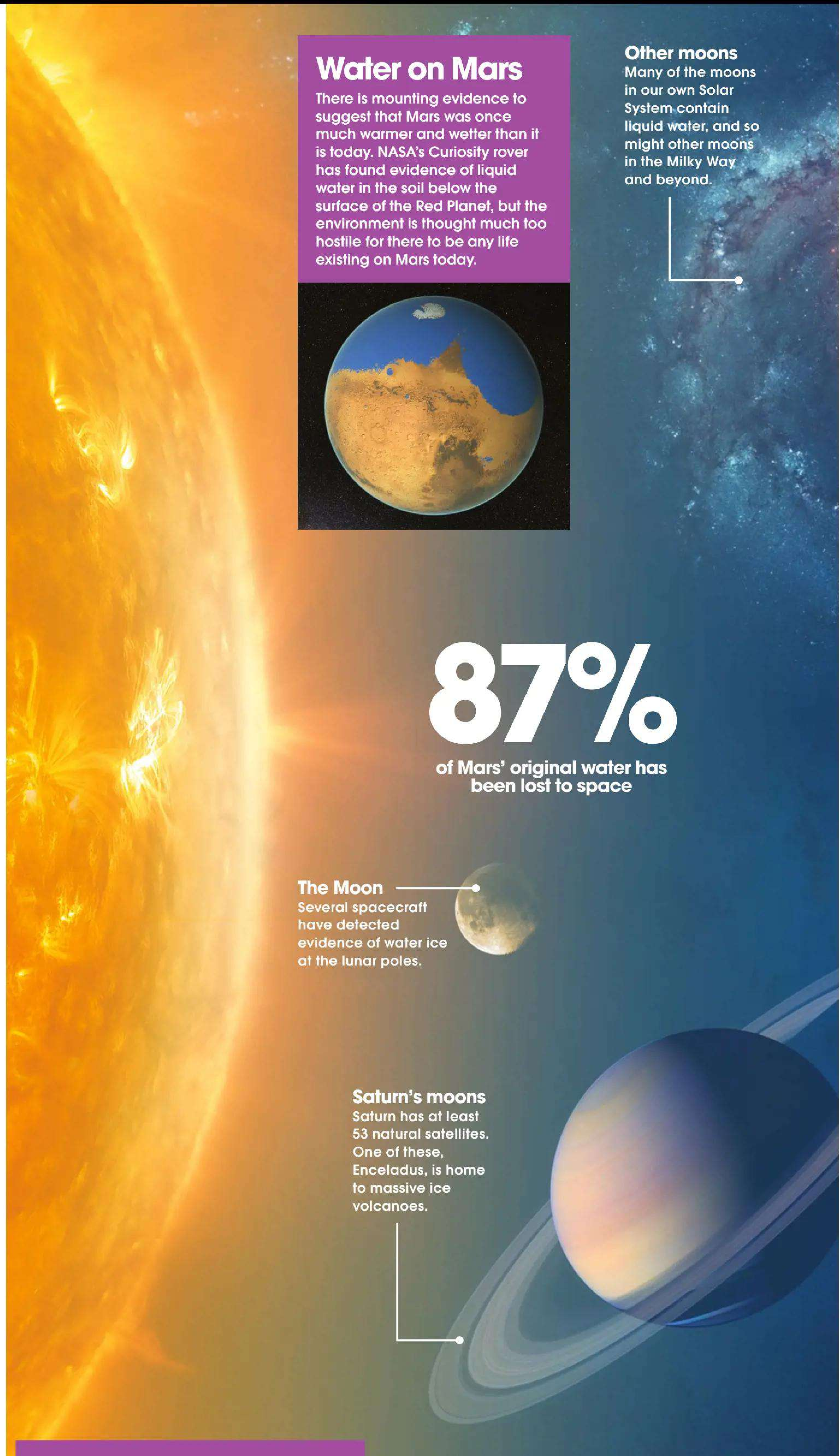
Water is quite unlike any other solvent in the known universe. Its chemical structure means that one side of each molecule is positively charged and the other is negatively charged. This makes water molecules sticky, attracting anything else with a positive or negative charge, including other water molecules and charged particles, like salts, for example.

There are other liquids that have been suggested as possible biological solvents, including methane, but none are quite like water. Because water is polar and its molecules are sticky, it can hold together as liquid at temperatures that would turn other similarly sized molecules to gas. Water remains liquid over a large range of temperatures, a property that has been vital for life on Earth.

In order for methane to be found in its liquid form, the temperature needs to be lower than -161 degrees Celsius . Liquid methane seas do exist on Saturn's moon Titan, but molecules at this temperature move around so little that biological reactions would have to occur in extreme slow motion.

The arrival of water on Earth was the catalyst that enabled life to evolve. Early Earth was hot and inhospitable, but around 400-600 million years after its formation, in the period known as the Late Heavy Bombardment, Earth was pummelled by rock and ice flung from the far reaches of the Solar System by the immense gravitational interactions of Jupiter, Saturn, Neptune and Uranus. The rocks brought ice with them, which melted to form liquid water.

All life discovered on Earth so far depends on this water for survival, so in the search for life elsewhere in the Solar System, scientists are focusing on finding water. If the conditions are right, liquid water on other planets or moons could have supported extraterrestrial life in the past, or possibly to this day.



Other galaxies
Water is quite common in the universe, and watery planets like our own are likely to exist in other galaxies.

Quasars
The largest reservoir of water in the known universe was found surrounding a black hole in a feeding frenzy.

Comets
These balls of frozen gas and dust contain water from the farthest reaches of the Solar System.

Habitable zone
Astronomers expect life to be most likely on planets that are the right distance from the Sun for liquid water to exist.

Asteroids
The asteroids that we see today contain little water, but earlier in the history of the Solar System they would have carried ice.

Space oceans

The largest oceans in the Solar System are found on moons

Europa
Moon of Jupiter
The intense gravitational pull of Jupiter causes friction on the icy moon Europa, generating enough heat to maintain liquid water below its surface. It is home to a vast ocean with more water than all of Earth's oceans combined.

Enceladus
Moon of Saturn
About seven times smaller than our own Moon, Enceladus is heated by the tidal effects of Saturn. Its geysers spit water vapour into space at speeds of about 400 metres (1,312 feet) per second.

Ganymede
Moon of Jupiter
Ganymede is larger than Mercury and is thought to be home to a sub-surface ocean that contains more water than there is on Earth's entire surface.

100km

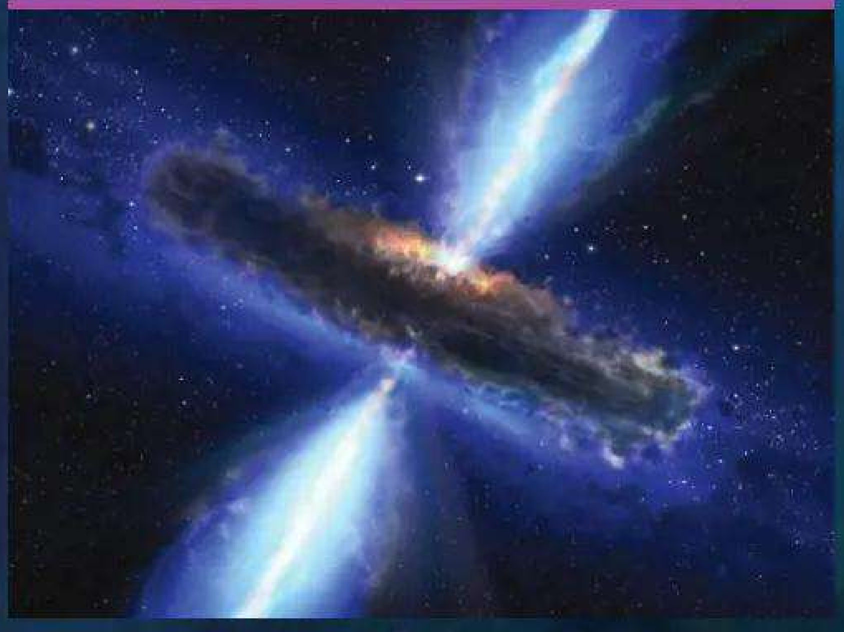
The thickness of Europa's sub-surface water layer

Water on Comets

We used to think that Earth's water came from comets, but in 2014 the European Space Agency's Rosetta probe discovered that the water on comets is different to the water on Earth. It is therefore more likely that water was delivered to the early Earth by rocky asteroids.

Water in space

The largest and most distant volume of water ever found in the universe is caught in the clutches of an enormous black hole, over 12 billion light years away. The cosmic reservoir hosts approximately 140 trillion times the amount of water there is in Earth's oceans.



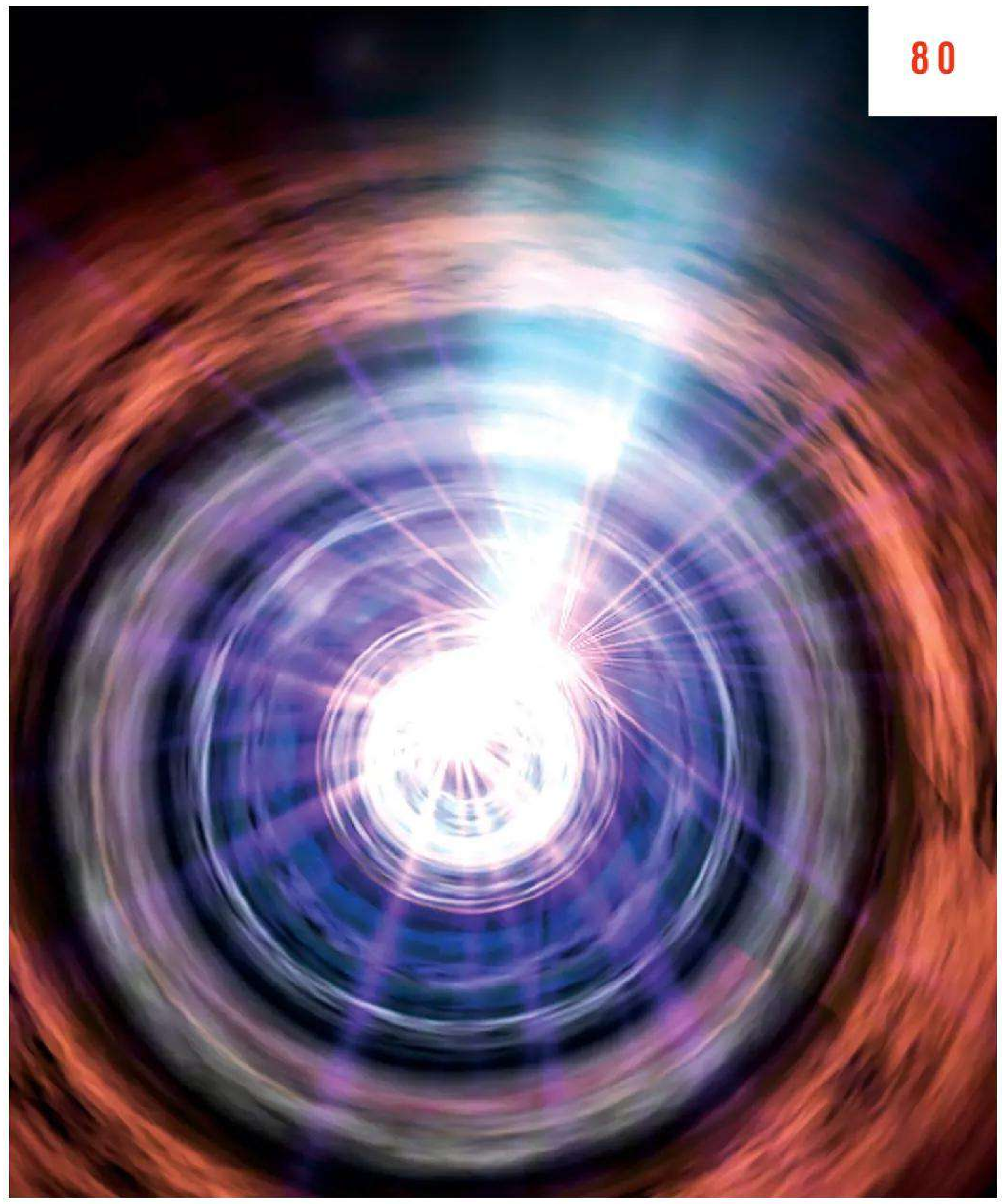
Nebulae
The ingredients of water, hydrogen and oxygen, are responsible for the colourful glow of some nebulae.

Star birth
Water can be found in the clouds of dust and gas that surround the birth of new stars.

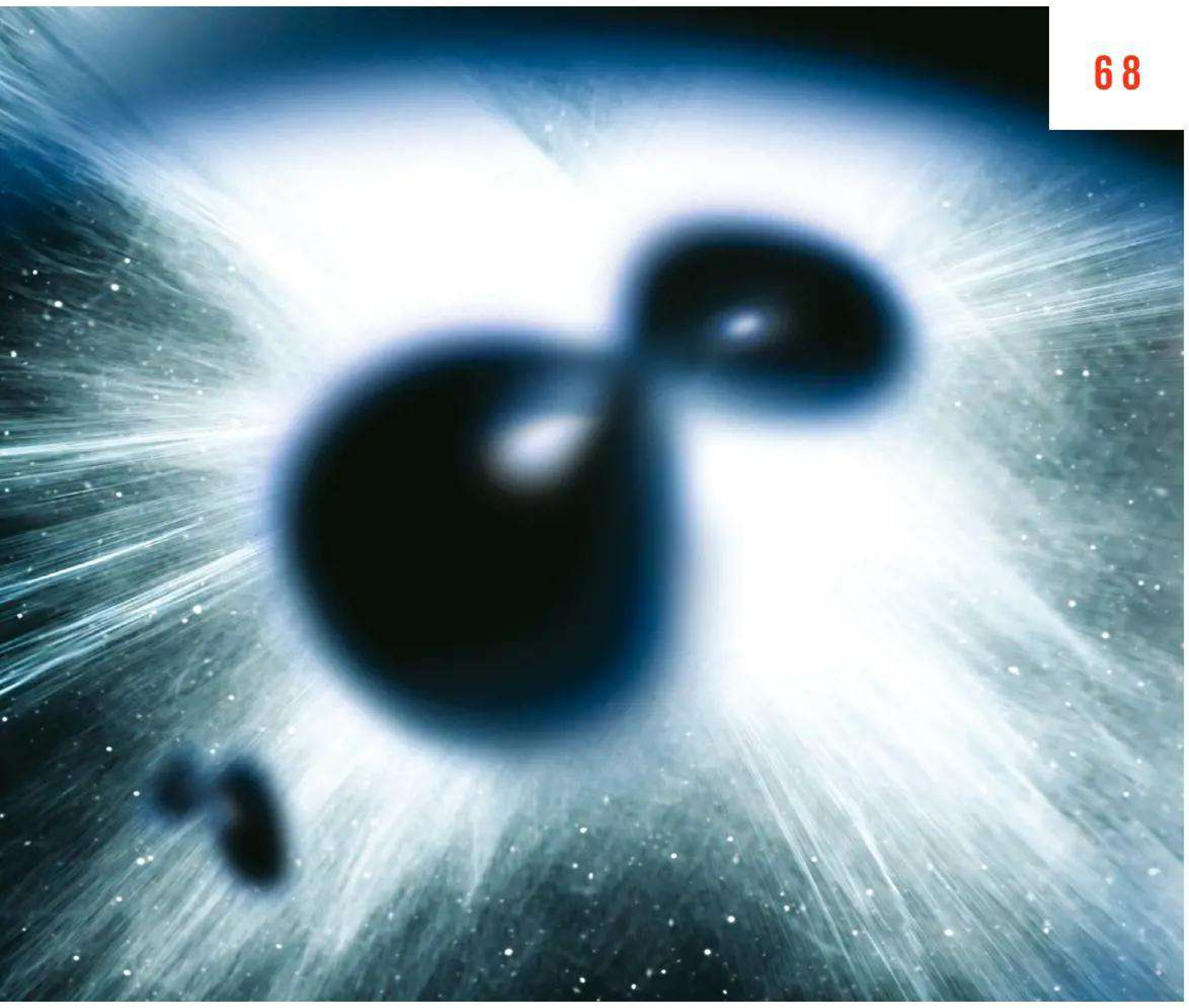
The Expanding Universe

62

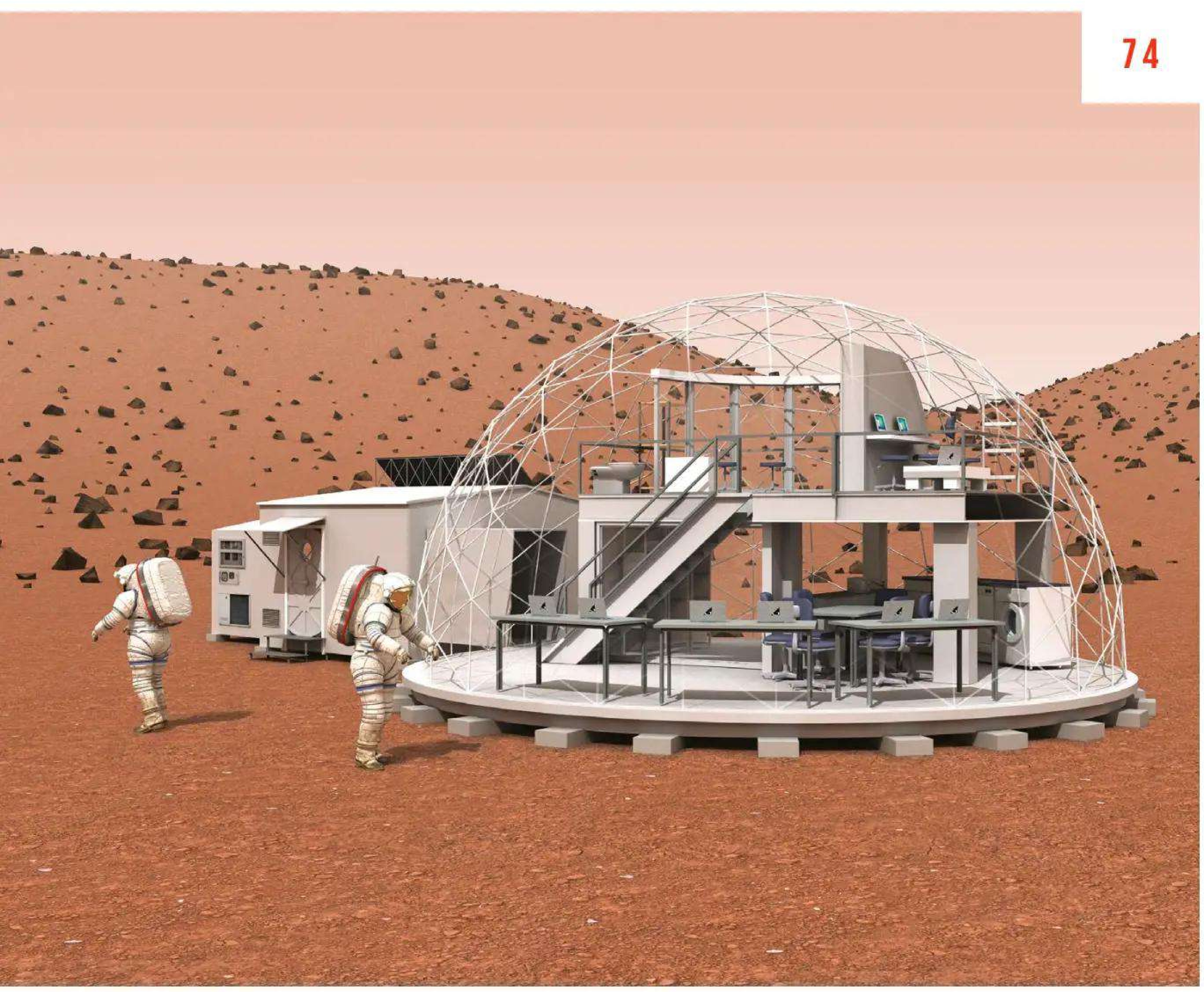
88



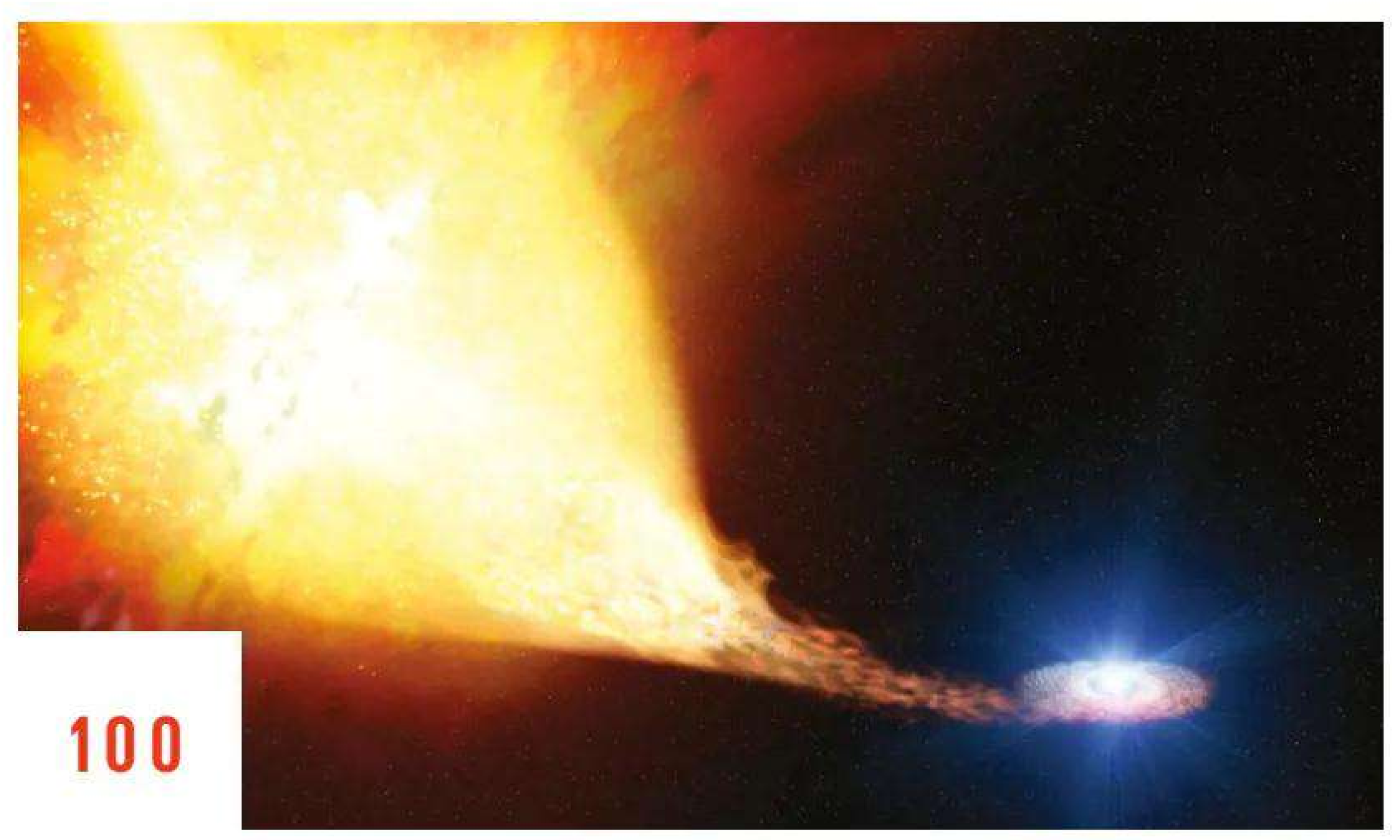
80



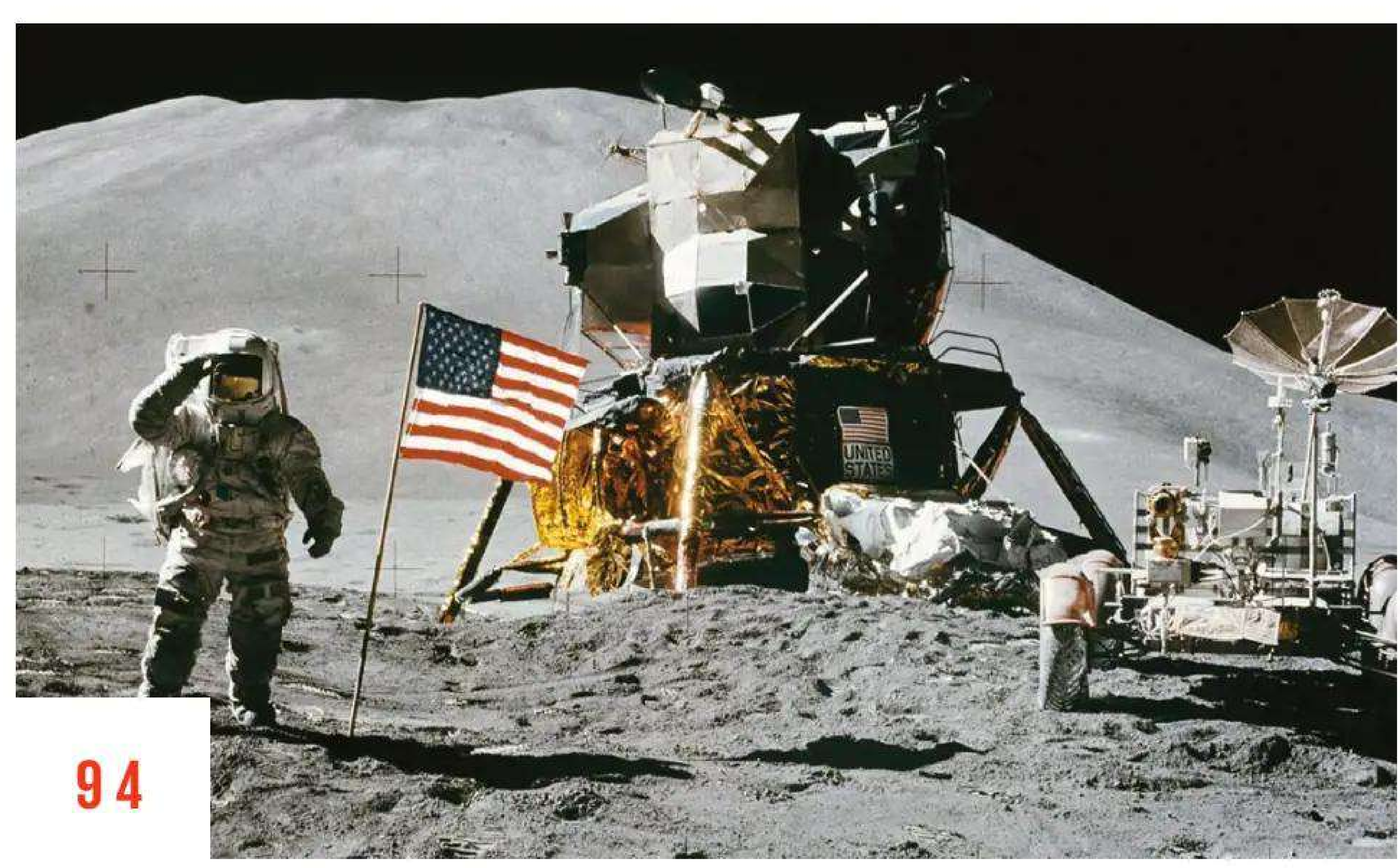
68



74



100



94

Guide to the galaxy

Home to our Solar System and billions of other stars and planets we reveal the Milky Way's origins and where we fit in now

Look up into the sky on a dark, clear night and every star you see is a part of our home galaxy – for the naked-eye observer, only a handful of tiny smudges of light mark objects in the wider universe. Dense, bright stars cluster along a faint river of light that ancient stargazers interpreted as a stream of milk spilt across the sky – the Milky Way that gives its name to our entire galaxy.

This distribution of stars gives us a good clue to its basic structure – viewed through binoculars, the Milky Way itself dissolves into clouds containing countless individual stars. Looking away from our galaxy, however, stars are relatively few and far between. This suggests that our Solar System is embedded in a more or less flat plane of stars – when we look across the plane, there are many stars stretching away over long distances in any given direction, while if we look 'above' or 'below', we see only the relatively nearby bodies of our galactic neighbourhood.

This was the basis for the first attempt to map our galaxy. In the 1770s and 1780s, German-born British astronomer William

The Milky Way has fascinated scientists and amateur astronomers alike for centuries

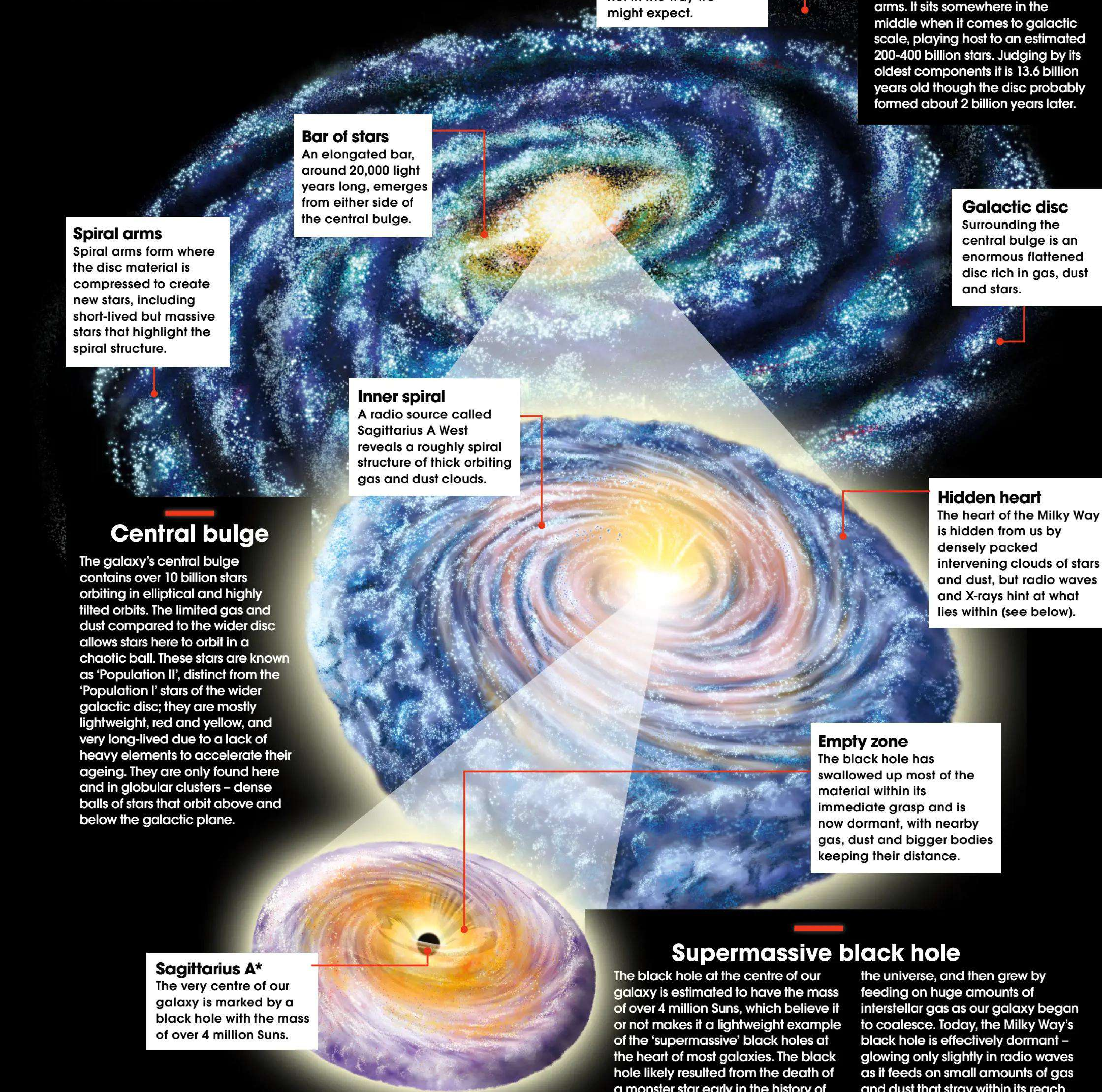
THE EXPANDING UNIVERSE

Anatomy of the Milky Way

To help you better understand the structure of our galaxy and its immense scale, here is an overview of the key components it is comprised of. It takes you from the farthest reaches of the galaxy, right into its mysterious core

Spiral galaxy

The Milky Way is a disc-shaped galaxy some 120,000 light years in diameter, with four major spiral arms. It sits somewhere in the middle when it comes to galactic scale, playing host to an estimated 200-400 billion stars. Judging by its oldest components it is 13.6 billion years old though the disc probably formed about 2 billion years later.



Central bulge

The galaxy's central bulge contains over 10 billion stars orbiting in elliptical and highly tilted orbits. The limited gas and dust compared to the wider disc allows stars here to orbit in a chaotic ball. These stars are known as 'Population II', distinct from the 'Population I' stars of the wider galactic disc; they are mostly lightweight, red and yellow, and very long-lived due to a lack of heavy elements to accelerate their ageing. They are only found here and in globular clusters – dense balls of stars that orbit above and below the galactic plane.

Supermassive black hole

The black hole at the centre of our galaxy is estimated to have the mass of over 4 million Suns, which believe it or not makes it a lightweight example of the 'supermassive' black holes at the heart of most galaxies. The black hole likely resulted from the death of a monster star early in the history of the universe, and then grew by feeding on huge amounts of interstellar gas as our galaxy began to coalesce. Today, the Milky Way's black hole is effectively dormant – glowing only slightly in radio waves as it feeds on small amounts of gas and dust that stray within its reach.

Herschel (discoverer of the planet Uranus) compiled detailed 'star counts' of different areas of the sky. Based on the faulty assumption that all stars had the same brightness, he eventually produced a chart that showed the Milky Way as a shapeless cloud with the Solar System at its centre.

Today, of course, our models are a lot more sophisticated. Herschel could hardly have dreamed that the Milky Way would eventually be mapped using radio waves, which were not even discovered until a century later. Since the Fifties, these waves have allowed astronomers to look beyond the star clusters and trace the distribution of huge clouds of hydrogen gas – a major component of the 'interstellar medium' that makes up the Milky Way's skeleton.

The biggest scientific breakthrough came with the discovery of galaxies beyond the Milky Way, back in the Twenties. Astronomers could now compare the Milky Way to other galaxies and it soon became clear that its properties were similar to those of so-called 'spiral nebulas', like the nearby Andromeda galaxy.

As a result, we now know that the Milky Way is a vast stellar pinwheel slowly spinning around a huge central bulge of old red and yellow stars. The visible part of the spiral is more than 100,000 light years across, with invisible material stretching out much farther. Our own Solar System is not at the centre, as Herschel thought, but halfway across the disc – 26,000 light years from the Milky Way's crowded core. And what's more, our Sun is just one fairly average, unremarkable star among 200 to 400 billion others.

Comparisons with other galaxies also suggest the Milky Way is a 'barred' spiral – its arms emerge from the ends of a dense bar of stars that stretches out on either side of the central bulge. The bulge is roughly spherical and about 16,000 light years across, while the bar is at least 20,000 light years long.

Surrounding the central bulge is a flattened disc of stars, about 1,000 light years deep, with the spiral arms running across it. In distant galaxies the arms are the only visible part of the disc, but the fainter background of more subdued stars and interstellar material must still be there, since it is this that ultimately gives rise to the spiral.

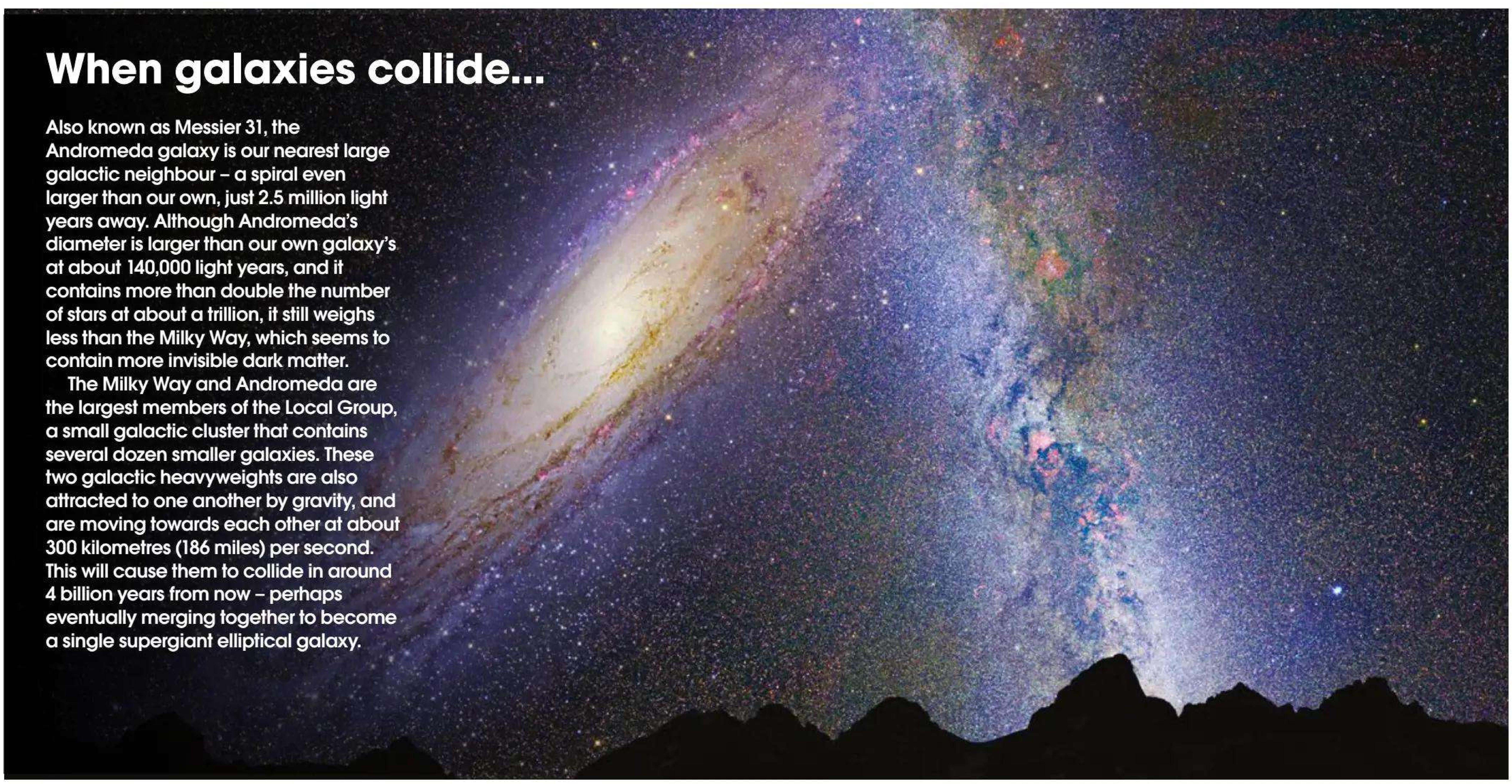
Despite appearances, the spiral arms cannot be solid structures – if they were, they would rapidly wind themselves up around the core, and we know from countless other galaxies that this simply doesn't happen.

Instead, it seems that the spiral arms are long-lived but constantly regenerating features – in a sense stellar 'traffic jams' where material in the disc clumps together. This not only concentrates the light of older 'disc stars' moving in and out of the spiral zone, but more importantly triggers new waves of star formation that give rise to future generations of brilliant but short-lived heavyweight stars.

These hot blue-white stars, clustered together as they emerge from starbirth nebulas, shine with the brightness of many thousands of Suns, but live and die in just a few million years – before their long orbits around the galaxy can carry them out of the spiral arm region. Only less massive and more sedate stars (like our Sun) live for long enough to emerge into the disc between the spiral arms.

But what actually causes the 'traffic jam' (known to astronomers as a density wave) in the first place? It appears to be a pattern that naturally arises when the slightly elliptical (stretched) orbits of disc stars and interstellar material are pulled in a particular direction by the gravity of another nearby galaxy. Because any orbiting object moves slowest on the outer

"Despite appearances, the spiral arms cannot be solid structures"



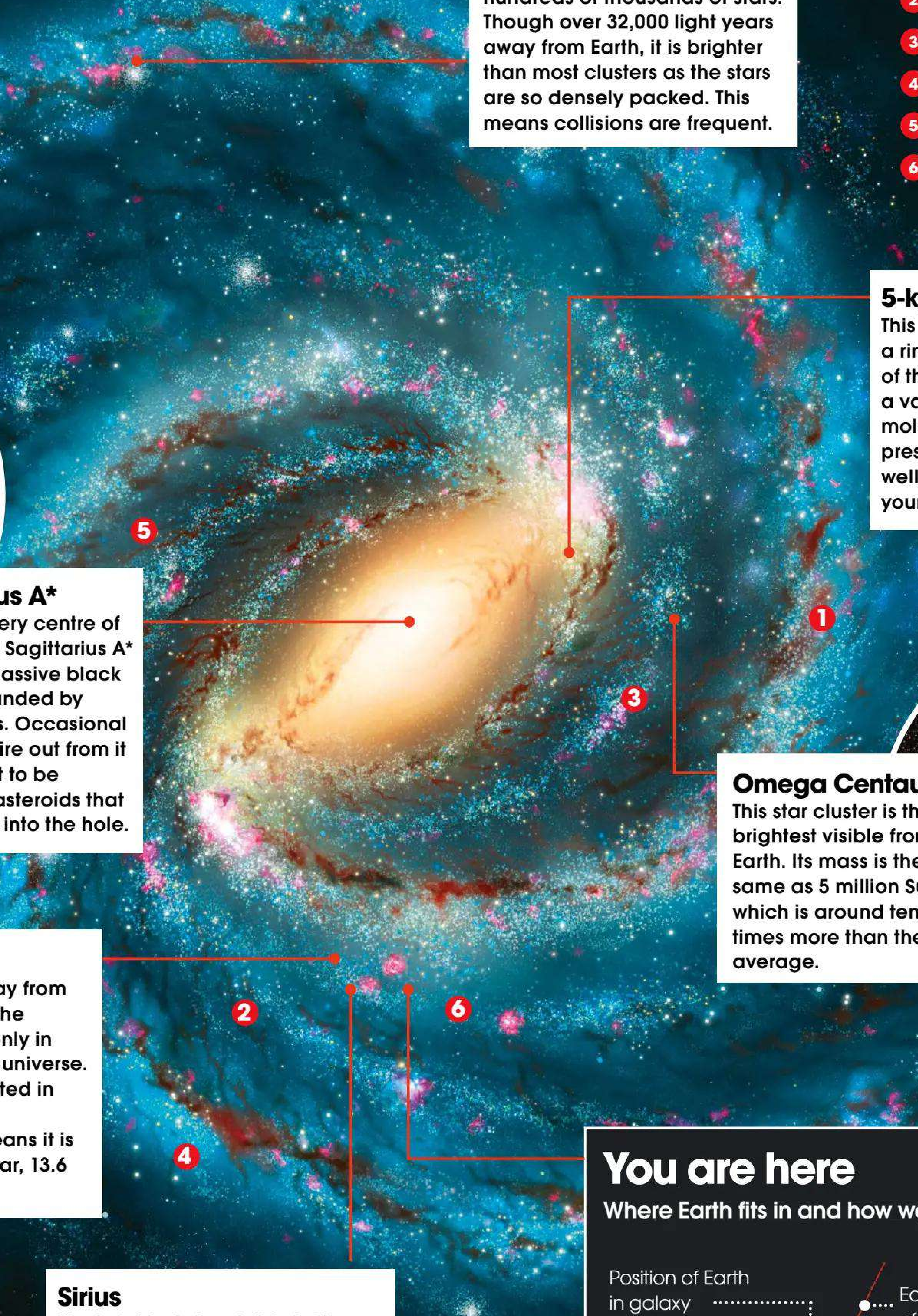
When galaxies collide...

Also known as Messier 31, the Andromeda galaxy is our nearest large galactic neighbour – a spiral even larger than our own, just 2.5 million light years away. Although Andromeda's diameter is larger than our own galaxy's at about 140,000 light years, and it contains more than double the number of stars at about a trillion, it still weighs less than the Milky Way, which seems to contain more invisible dark matter.

The Milky Way and Andromeda are the largest members of the Local Group, a small galactic cluster that contains several dozen smaller galaxies. These two galactic heavyweights are also attracted to one another by gravity, and are moving towards each other at about 300 kilometres (186 miles) per second. This will cause them to collide in around 4 billion years from now – perhaps eventually merging together to become a single supergiant elliptical galaxy.

Sights not to miss...

From record-breaking stars to amazing clusters, we pick out some of the standout phenomena to be found in our galaxy



Messier 80

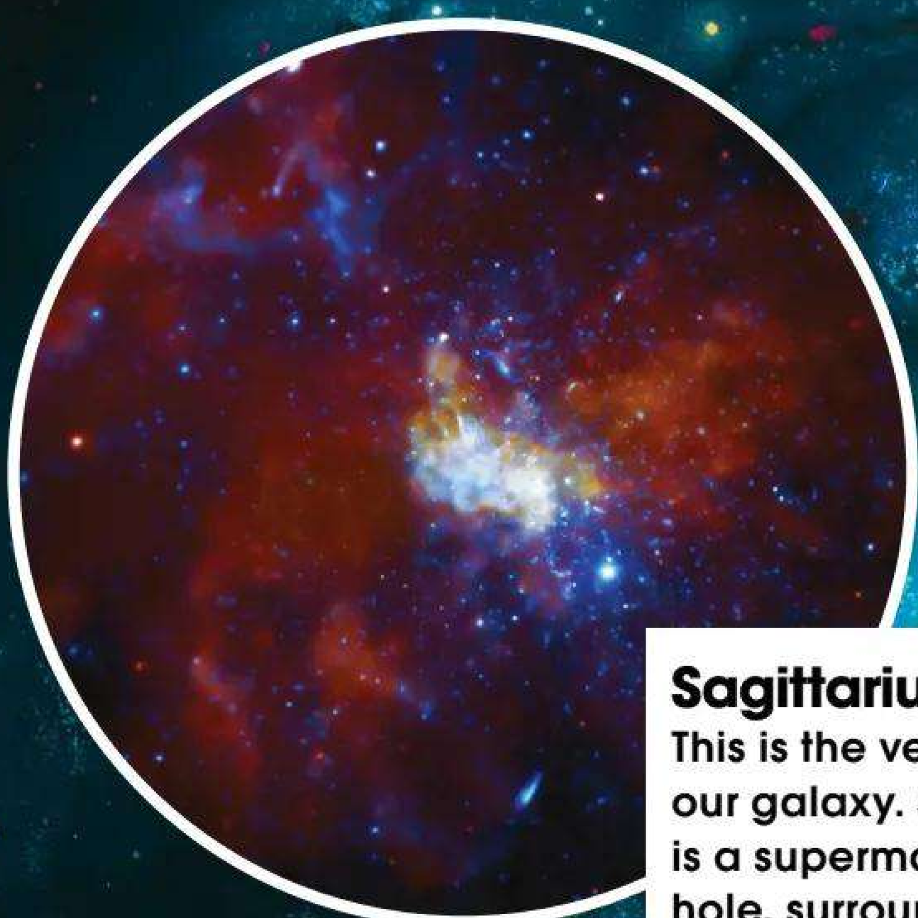
This globular cluster about 95 light years across is home to hundreds of thousands of stars. Though over 32,000 light years away from Earth, it is brighter than most clusters as the stars are so densely packed. This means collisions are frequent.

Key to the arms

1. Scutum-Centaurus Arm
2. Perseus Arm
3. Norma Arm
4. Outer Arm
5. Sagittarius Arm
6. Orion Arm

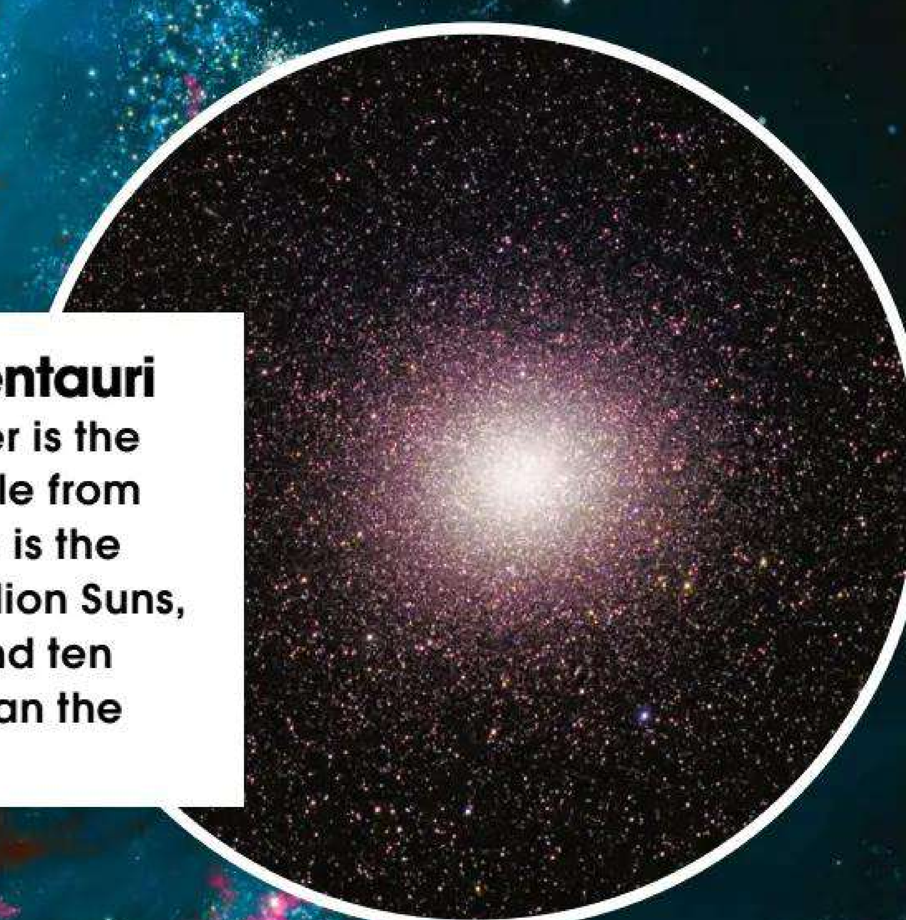
5-kpc ring

This superstructure forms a ring around the centre of the galaxy. It contains a vast percentage of the molecular hydrogen present in the galaxy as well as between 100-200 young stars.



Sagittarius A*

This is the very centre of our galaxy. Sagittarius A* is a supermassive black hole, surrounded by swirling gas. Occasional flares that fire out from it are thought to be vaporised asteroids that get sucked into the hole.



Omega Centauri

This star cluster is the brightest visible from Earth. Its mass is the same as 5 million Suns, which is around ten times more than the average.

SM0313

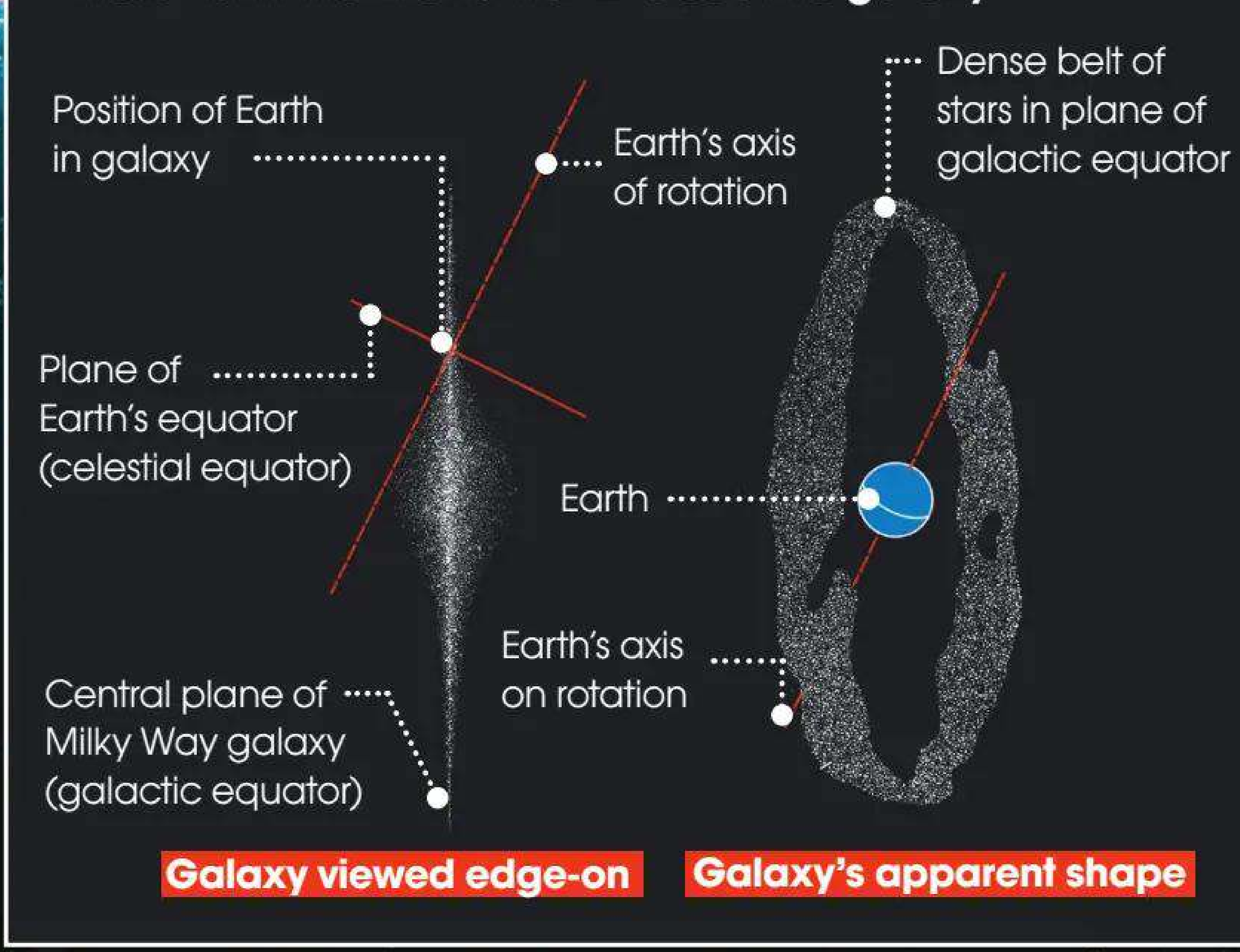
A mere 6,000 light years away from our Solar System, SM0313 is the oldest star we know of, not only in our galaxy, but in the whole universe. The discovery was first reported in January 2014 and its near nonexistent levels of iron means it is likely to be a Population II star, 13.6 billion years old.

Sirius

The brightest star visible in the night sky. Its visual magnitude, the brightness of an object taking into account its distance from the viewer, is -1.47. For comparison, the maximum brightness of a full Moon is -12.6 and the maximum brightness of Saturn is only -0.49.

You are here

Where Earth fits in and how we see the galaxy



part of its orbit, this kind of tugging eventually means that everything is slowing down in the same place, giving rise to the spiral traffic jam.

And there are plenty of nearby galaxies to do the hard work – our Milky Way is surrounded by more than a dozen smaller satellites under its gravitational pull. The most famous of these are the Magellanic Clouds, two irregular clouds of gas and stars that lie 160,000 and 200,000 light years from Earth and look like isolated chunks of the Milky Way in southern skies. Just as influential are the much smaller Sagittarius Dwarf Elliptical and Canis Major Dwarf galaxies, both of which are currently colliding with, and ultimately being absorbed by, our own spiral.

Everything in the Milky Way is in constant motion. Stars in the central bulge travel in tilted and stretched orbits around the huge concentration of mass in the core, while farther out, stars in the disc tend to follow flatter, more circular orbits. An important reason for this difference is that the disc is a mix of stars, gas and dust; stars on their own can follow more chaotic orbits with little risk of collision with their neighbours, but clouds of gas and dust collide all the time. This tends to force them into uniform motion, and since the disc stars originate from within the gas and dust clouds, they tend to inherit their movement.

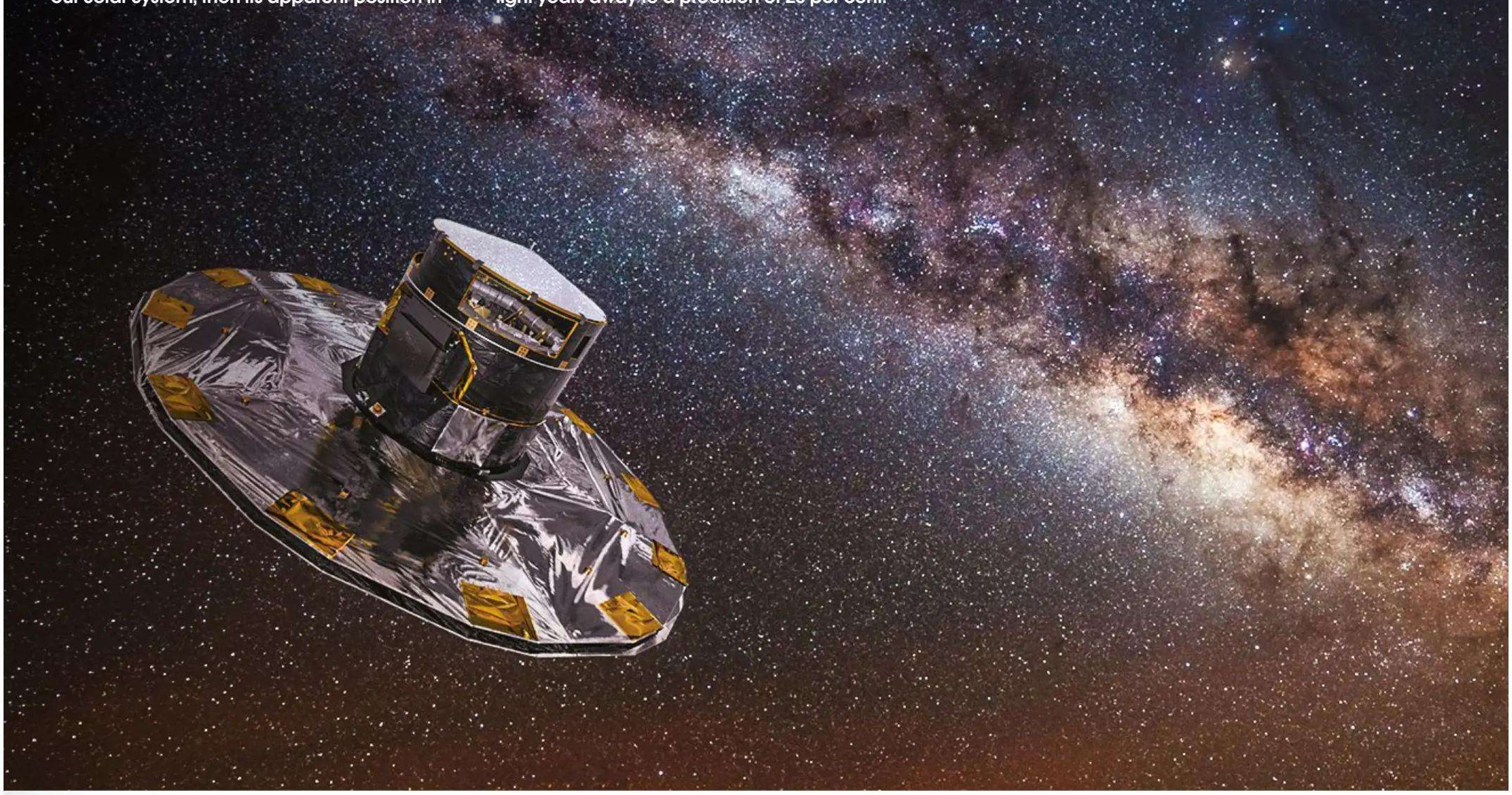
While the speed of orbiting stars changes with distance from the centre, it doesn't do so in quite the way we'd expect, presenting another puzzle. Stars across most of the disc move at more or less the same speed, rather than moving much more slowly at greater distances from the core. This suggests that the distribution of mass in our galaxy doesn't match the distribution of its visible matter, and that there's a huge amount of invisible material beyond the confines of the visible Milky Way. Astronomers call this mysterious substance 'dark matter', and there's good evidence that it outweighs visible matter in our galaxy by a factor of ten to one.

Looking in the opposite direction, toward the galactic centre, stellar orbits also help us probe the core of our galaxy. Here, stars seem to move constantly faster and faster, suggesting an immense concentration of mass at the very centre of our galaxy, coinciding with a source of radio waves and X-rays known as Sagittarius A*. This is now known to be an enormous black hole with the mass of over 4 million Suns compressed in a region far smaller than the Solar System – the dark secret at the heart of our fascinating galaxy.

Gaia: mapping the Milky Way

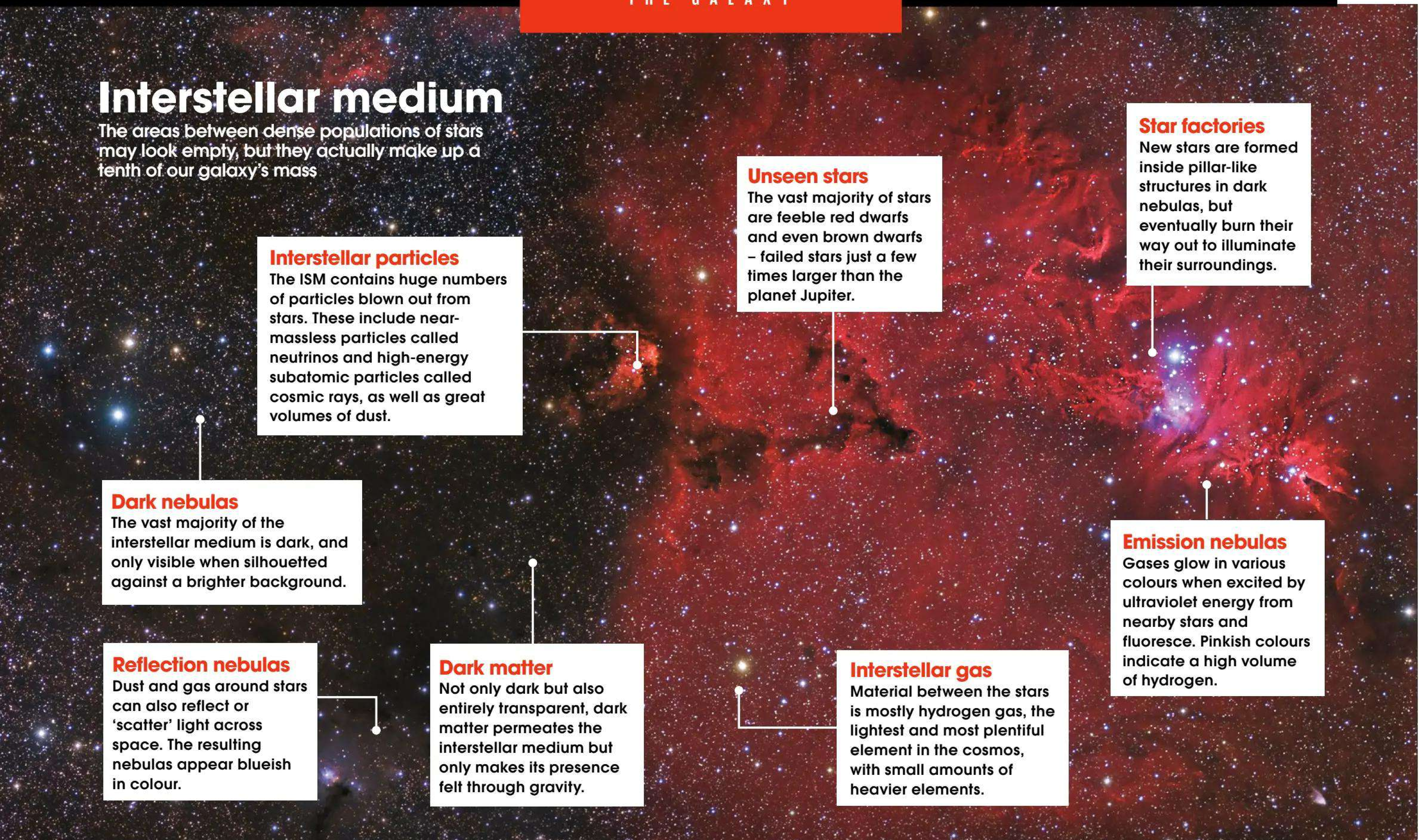
In December 2013, the European Space Agency launched a satellite that aims to revolutionise our view of the Milky Way. Gaia is a space telescope designed to survey more than a billion stars, compiling the most detailed map of our galaxy to date. It reached its operational orbit, some 150 million kilometres (93.2 million miles) from Earth, in January 2014.

Gaia uses a geometric technique known as the parallax method. If a star is close enough to our Solar System, then its apparent position in the sky will change very slightly when viewed from opposite sides of Earth's orbit (the same effect makes your outstretched finger appear to shift against more distant objects when you view it through one eye and then the other). By measuring this 'parallax shift' it's possible to calculate the star's distance using simple geometry. For all but the closest stars, the angles involved are absolutely tiny, but Gaia will still be able to measure objects up to 30,000 light years away to a precision of 20 per cent.



Interstellar medium

The areas between dense populations of stars may look empty, but they actually make up a tenth of our galaxy's mass



Interstellar particles
The ISM contains huge numbers of particles blown out from stars. These include near-massless particles called neutrinos and high-energy subatomic particles called cosmic rays, as well as great volumes of dust.

Unseen stars
The vast majority of stars are feeble red dwarfs and even brown dwarfs – failed stars just a few times larger than the planet Jupiter.

Star factories
New stars are formed inside pillar-like structures in dark nebulas, but eventually burn their way out to illuminate their surroundings.

Dark nebulas
The vast majority of the interstellar medium is dark, and only visible when silhouetted against a brighter background.

Emission nebulas
Gases glow in various colours when excited by ultraviolet energy from nearby stars and fluoresce. Pinkish colours indicate a high volume of hydrogen.

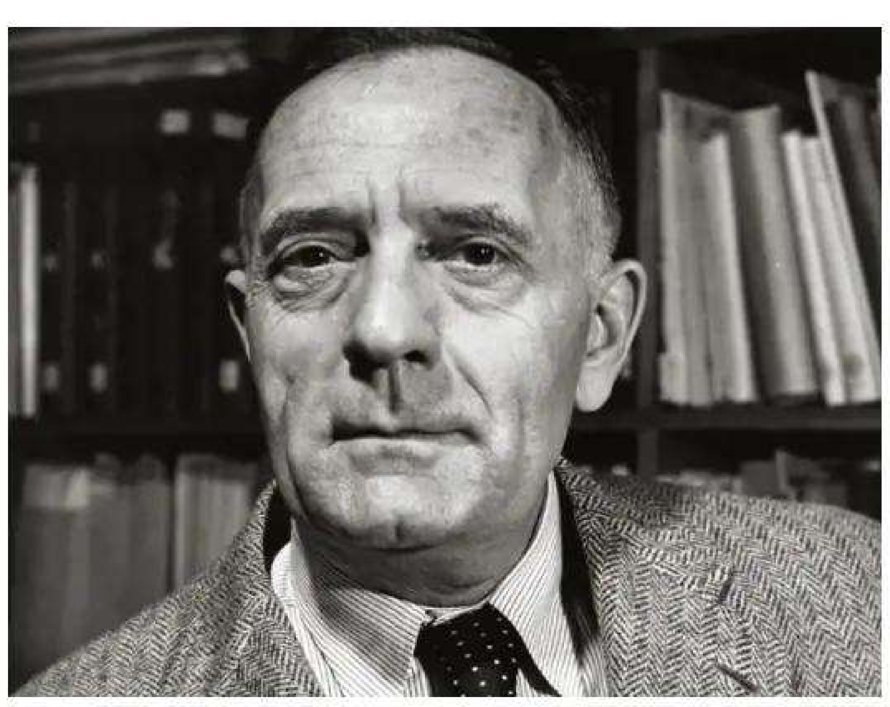
Reflection nebulas
Dust and gas around stars can also reflect or 'scatter' light across space. The resulting nebulas appear blueish in colour.

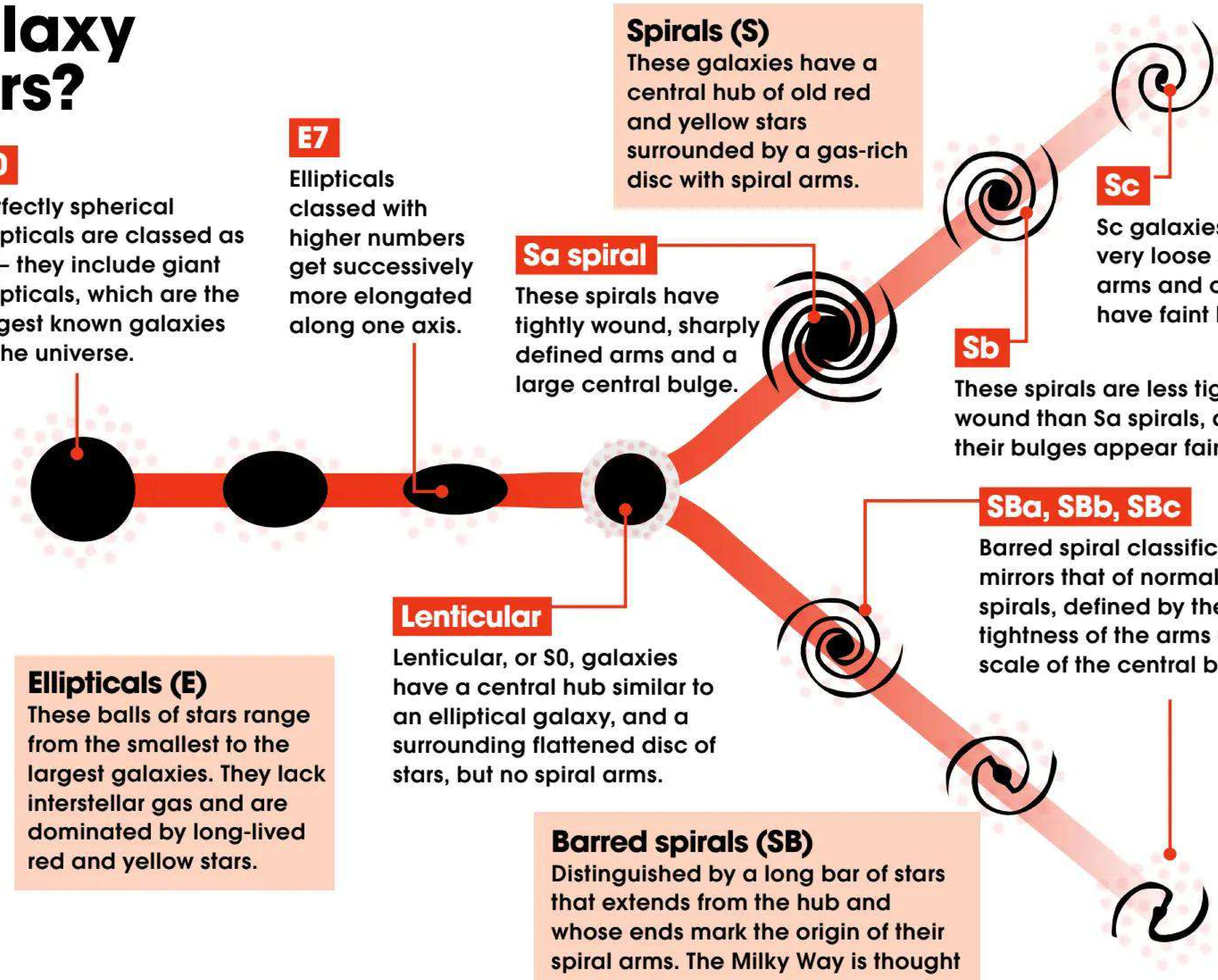
Dark matter
Not only dark but also entirely transparent, dark matter permeates the interstellar medium but only makes its presence felt through gravity.

Interstellar gas
Material between the stars is mostly hydrogen gas, the lightest and most plentiful element in the cosmos, with small amounts of heavier elements.

How does our galaxy shape up to others?

Edwin Hubble, the US astronomer who first proved the existence of galaxies beyond the Milky Way, soon recognised several different types and developed a classification system that has largely stood the test of time. Spirals were split into two broad groups – normal and barred – each further divided depending on the tightness and definition of their spiral arms. Elliptical or ball-shaped galaxies were classed by their shape, from the perfectly spherical to the highly elliptical. Hubble laid the galaxies out in what is known as a 'tuning fork' diagram, which he believed charted a pattern of galaxy evolution. We now know that the true life cycle of galaxies is even more complex than Hubble suspected.





E0
Perfectly spherical ellipticals are classed as E0 – they include giant ellipticals, which are the largest known galaxies in the universe.

E7
Ellipticals classed with higher numbers get successively more elongated along one axis.

Spirals (S)
These galaxies have a central hub of old red and yellow stars surrounded by a gas-rich disc with spiral arms.

Sa spiral
These spirals have tightly wound, sharply defined arms and a large central bulge.

Sc
Sc galaxies show very loose spiral arms and only have faint bulges.

Sb
These spirals are less tightly wound than Sa spirals, and their bulges appear fainter.

SBa, SBb, SBc
Barred spiral classification mirrors that of normal spirals, defined by the tightness of the arms and scale of the central bulge.

Lenticular
Lenticular, or S0, galaxies have a central hub similar to an elliptical galaxy, and a surrounding flattened disc of stars, but no spiral arms.

Ellipticals (E)
These balls of stars range from the smallest to the largest galaxies. They lack interstellar gas and are dominated by long-lived red and yellow stars.

Barred spirals (SB)
Distinguished by a long bar of stars that extends from the hub and whose ends mark the origin of their spiral arms. The Milky Way is thought to sit between SBb and SBc.

THE EXPANDING UNIVERSE

The mystery of dark matter

Hunting for the invisible mass that makes up 85 per cent of matter in the universe

Out there in the universe, something is going on that we're not able to fully explain. Over three billion light years away from Earth, two great clusters of galaxies are colliding. The stars in both are relatively unaffected in the melee, but clouds of hot, X-ray emitting gas are crashing into one another, stitching the two galaxy clusters into one new one: meet the Bullet Cluster, one of the most energetic events in the cosmos. Yet amid the epic confrontation of the clusters, something mysterious lurks, something for which the only name we have is 'dark matter'.

Within the Bullet Cluster we can see the galaxies. We can see the gas, which actually makes up most of the mass that emits light, more than even the galaxies. But there is a completely invisible component – dark matter – yet its presence is perhaps the most crucial.

Dark matter's name implies that this mysterious substance is dark, but it is more than that – it is invisible, refusing to emit or absorb any forms of light or radiation that could reveal its existence and end its game of hide-and-seek. It passes straight through ordinary matter. We cannot smell, taste, touch or see it. What we do know is that it accounts for 27 per cent of all the mass and energy within the universe (normal matter is only five per cent and dark energy, which is the mysterious force accelerating the expansion of the universe, makes up the remaining 68 per cent) and it's likely to be made of some form of undiscovered subatomic particle.

"Little is known about it and all that the numerous searches for dark matter particles have done is rule out various hypotheses, but there have never been any 'positive' results", says astrophysicist Maxim Markevitch, who has carefully studied the Bullet Cluster for the effects of dark matter using NASA's Chandra X-ray Observatory.

However, there is one way in which it grabs our attention, which is through the force of gravity. One of the effects of this is clearly played out in the Bullet Cluster. It is this that allows astronomers to work out where the

> **"It is invisible, refusing to emit or absorb any forms of light or radiation that could reveal its existence"**

dark matter in the Bullet Cluster is located, even though we cannot even see it.

Albert Einstein's General Theory of Relativity described how mass can bend space. Some people like to use the analogy of a cannonball on a sheet of rubber – the cannonball causes the sheet to sag. If you imagine the ball is an object like a galaxy or a star and the rubber sheet as space, you can see how mass bends space.

However, light prefers to take straight paths through the universe, so what happens when it arrives at a region of space that has been warped in this manner? The light will follow the path of curved space, bending its trajectory. In this way a massive object in space can act like a lens, bending and magnifying light. This effect was predicted by Einstein nearly 100 years ago and we call these gravitational lenses.

Because galaxy clusters are so huge, they create formidable gravitational lenses. They can magnify the light of even more distant galaxies, but it is not a clear image, rather distorted arcs or smudges of light and occasionally a complete ring. We can see gravitational lensing by the Bullet Cluster, magnifying the light of distant galaxies.

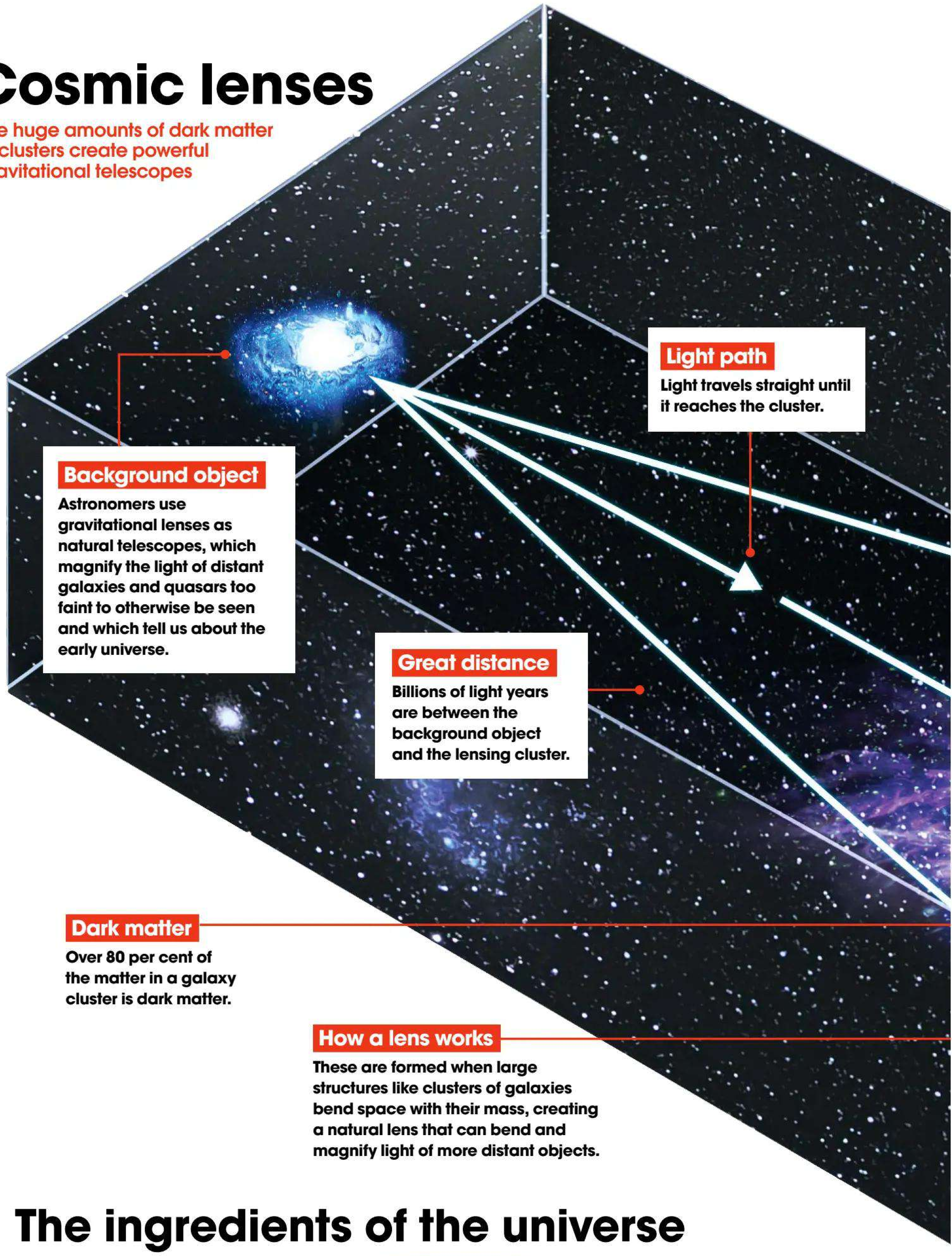
But when scientists analysed the gravitational lens, they found something stunning – the lensing effect was too strong to be accounted for by the mass of only the galaxies and the gas. There must be some other type of mass there, hidden. This is dark matter. From the pattern of the lensing, it is possible to work out where the dark matter in the cluster is, which has lead to another remarkable discovery. As the clusters collided, the galaxies and the gas have begun to merge, but the dark matter surrounding each cluster has slid silently through, not interacting with anything at all.

The Bullet Cluster was not the first time we saw the effects of dark matter. That discovery goes all the way back to 1933 when famous astronomer Fritz Zwicky at the California Institute of Technology (Caltech) noticed that galaxies orbiting around the edge of galaxy clusters were moving faster than they should.

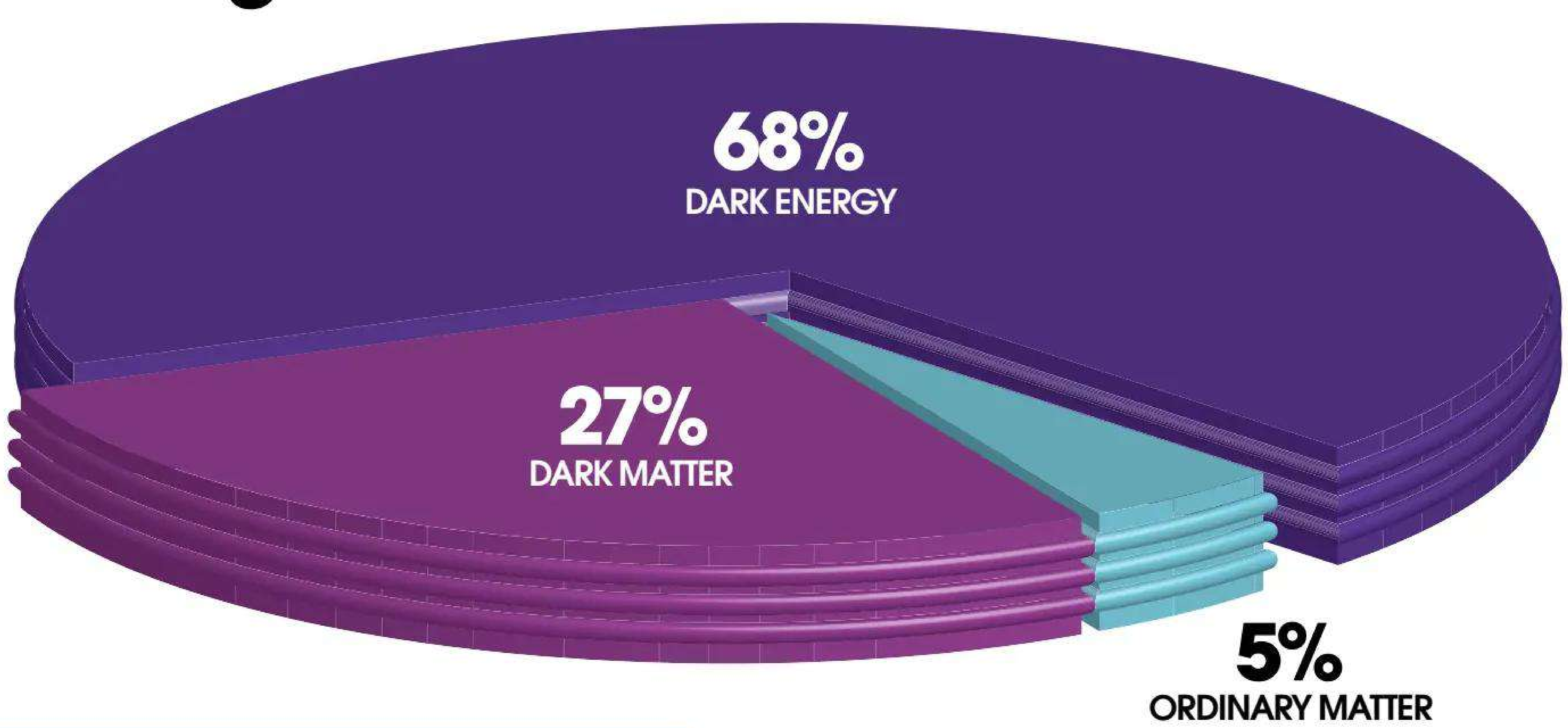
Why should they be moving at a particular speed? In the 17th century, Johannes Kepler devised his laws of orbital motion, the third one being that "the square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit". In other words, the farther from the Sun, and therefore the centre of mass of the Solar System, the slower a planet orbits. This should

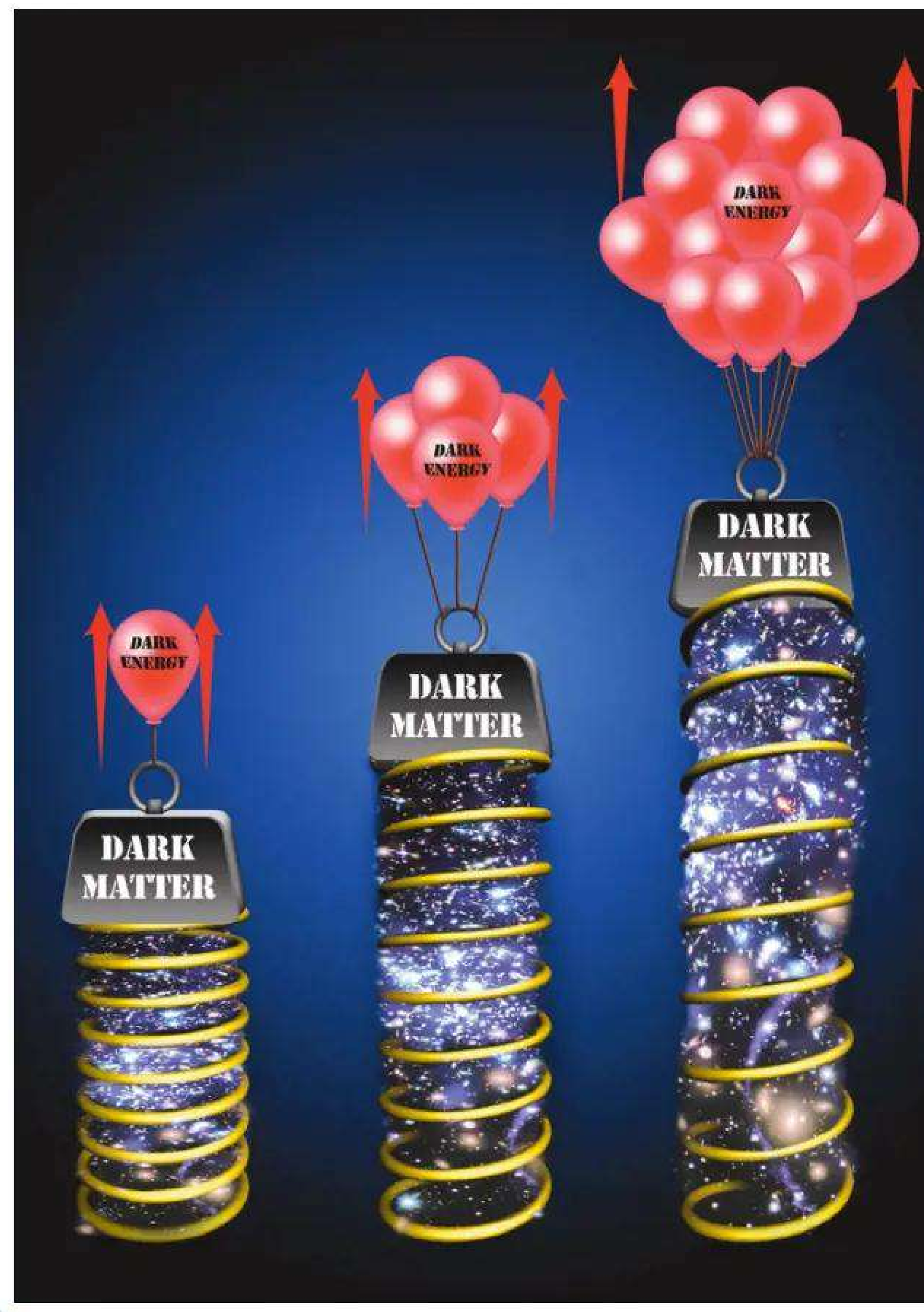
Cosmic lenses

The huge amounts of dark matter in clusters create powerful gravitational telescopes



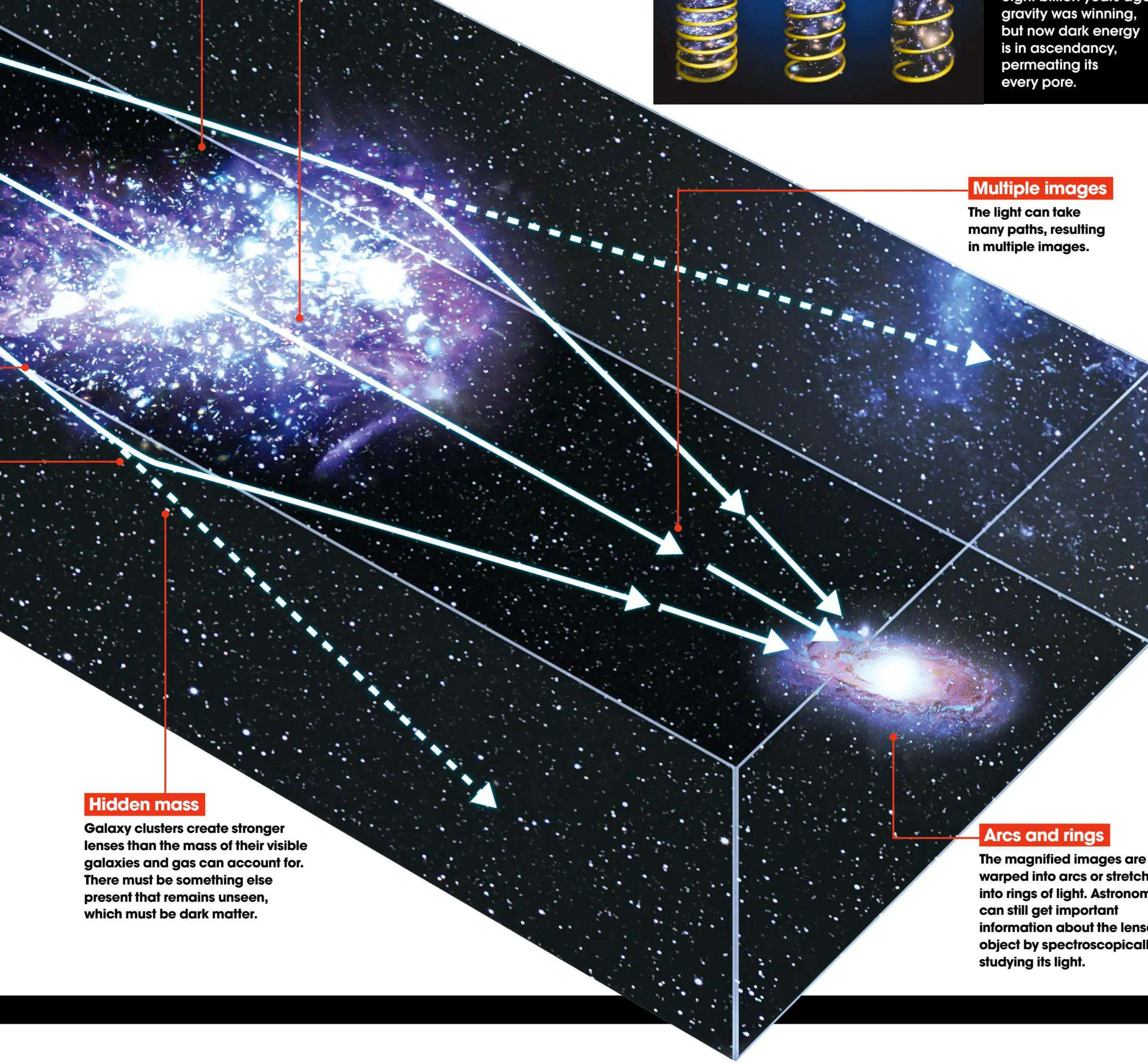
The ingredients of the universe





Expanding universe

Gravity and dark energy are engaged in a war for the universe. Gravity, primarily from dark matter but also ordinary matter and black holes, is trying to slow and reverse the expansion of the universe. Meanwhile, dark energy is trying to accelerate it and push the many galaxies that occupy it, away from us. Until eight billion years ago gravity was winning, but now dark energy is in ascendancy, permeating its every pore.



Magnifying lens
Space is curved by the cluster, so light follows a curved path.

Galaxies
Galaxy clusters can contain hundreds or thousands of galaxies.

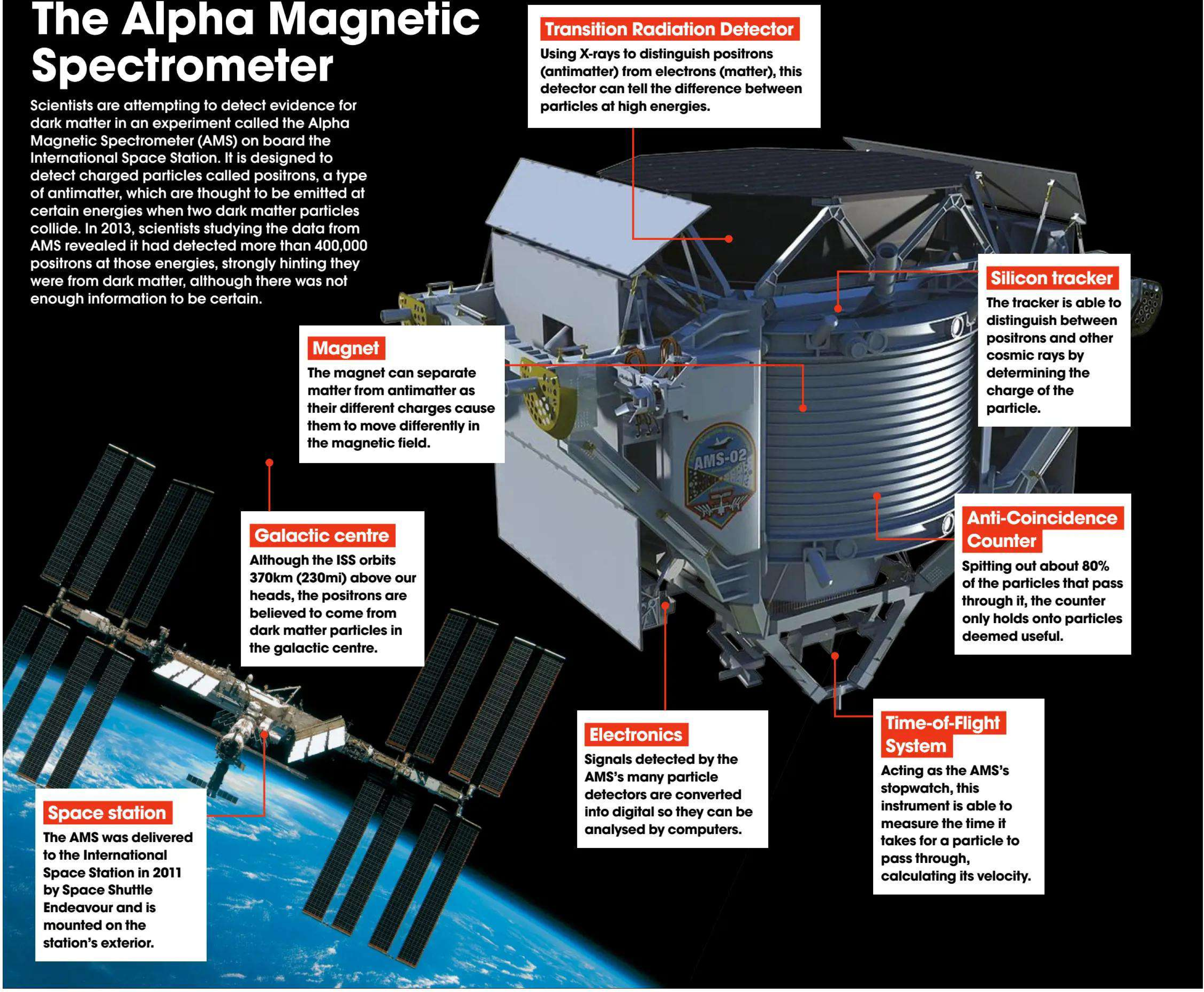
Multiple images
The light can take many paths, resulting in multiple images.

Hidden mass
Galaxy clusters create stronger lenses than the mass of their visible galaxies and gas can account for. There must be something else present that remains unseen, which must be dark matter.

Arcs and rings
The magnified images are warped into arcs or stretched into rings of light. Astronomers can still get important information about the lensed object by spectroscopically studying its light.

The Alpha Magnetic Spectrometer

Scientists are attempting to detect evidence for dark matter in an experiment called the Alpha Magnetic Spectrometer (AMS) on board the International Space Station. It is designed to detect charged particles called positrons, a type of antimatter, which are thought to be emitted at certain energies when two dark matter particles collide. In 2013, scientists studying the data from AMS revealed it had detected more than 400,000 positrons at those energies, strongly hinting they were from dark matter, although there was not enough information to be certain.



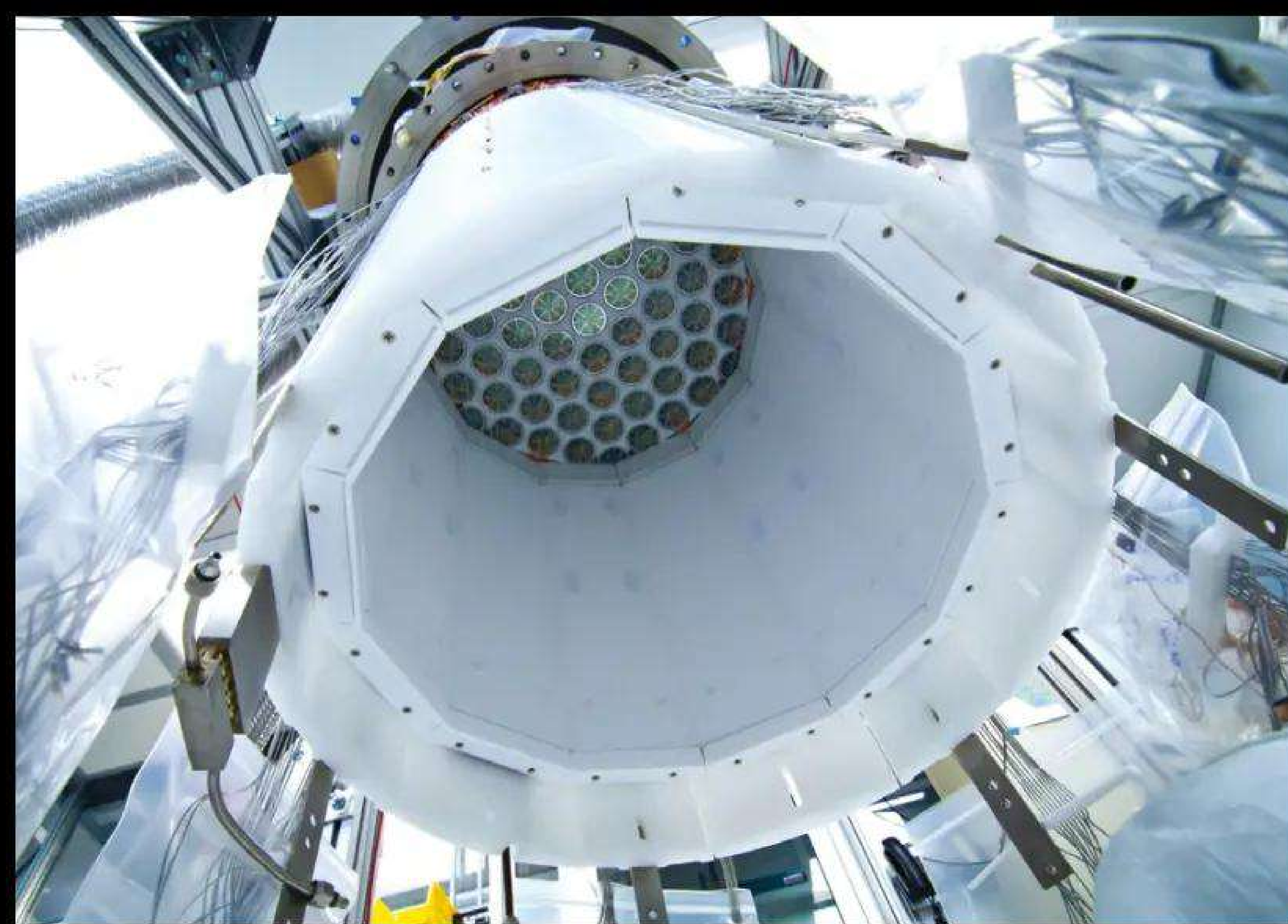
also be the case for galaxies orbiting galaxy clusters, but Zwicky found that galaxies on the edges of clusters were orbiting just as fast as those closer in. This implied there must be some unseen mass in the cluster helping things along with its gravity. He called this dark matter, but his idea was generally ignored. It was only in the 1970s when astronomer Vera Rubin of the Carnegie Institution for Science noticed the same problem with the orbits of stars and gas near the edges of galaxies. This time the problem was noticed and today dark matter is one of the biggest puzzles of cosmology. Dark matter now forms an integral part of our models of how galaxies grow – we envisage galaxies in halos of dark matter, which is spread across the universe in a great cosmic web, pulling matter toward it and making galaxies and clusters expand.

The Bullet Cluster holds the best evidence for dark matter, but astronomers and particle physicists seeking to shed light on this substance are building new experiments to try to catch dark matter so we can finally find out what it is. Although evidence from space suggests that dark matter does not interact with ordinary matter on large scales, physicists suspect that on the scale of individual particles, dark matter sometimes does interact. There must be trillions of these particles passing through us every moment, but the interactions are so rare that scientists may have to wait years to see one. Physicists describe these particles as WIMPs, an abbreviation that stands for weakly interacting massive particles.

In order to trap a dark matter particle in the act, most experiments take place far underground, away from any cosmic ray radiation on the surface that could

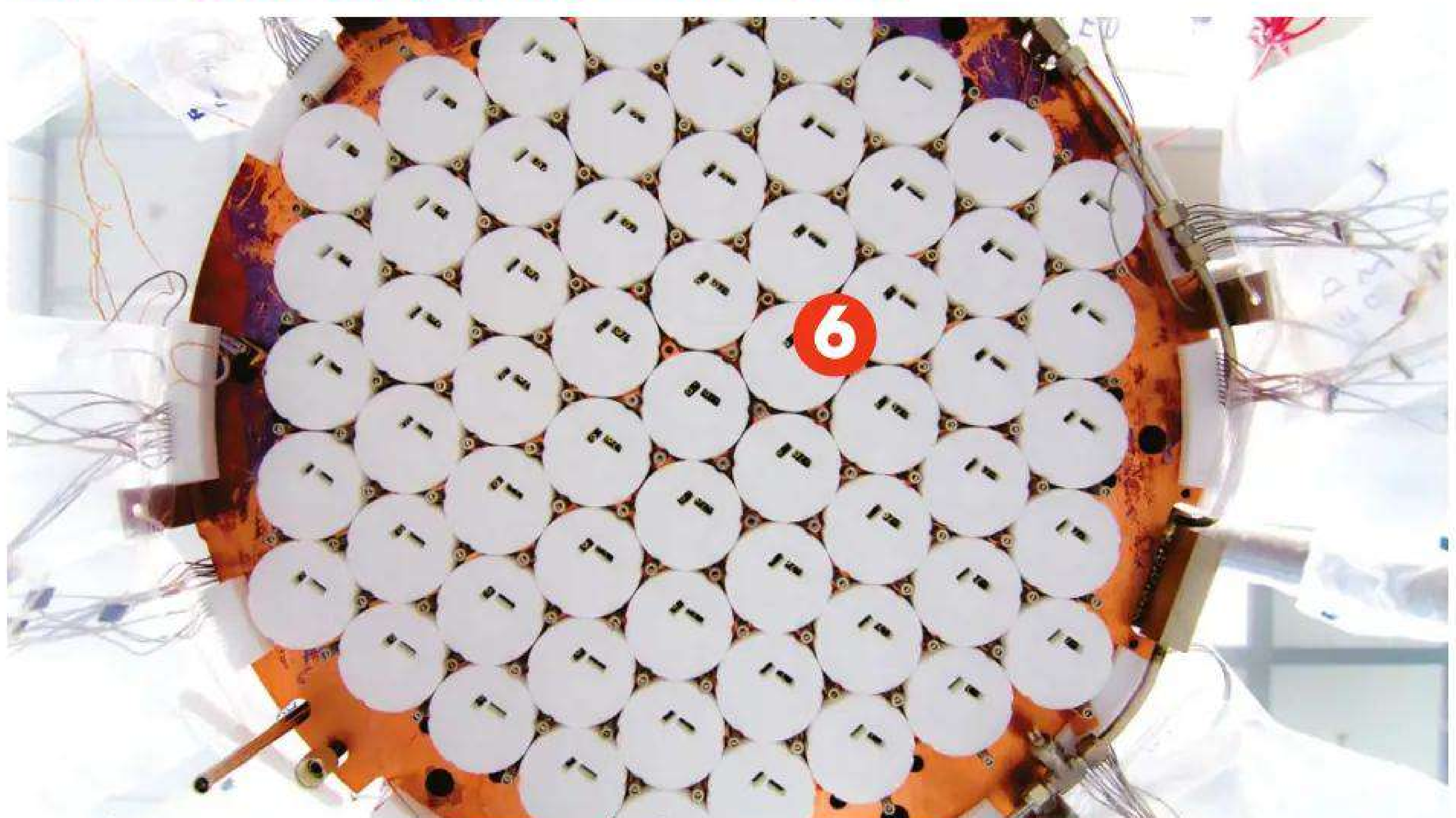
Dark matter is for WIMPs

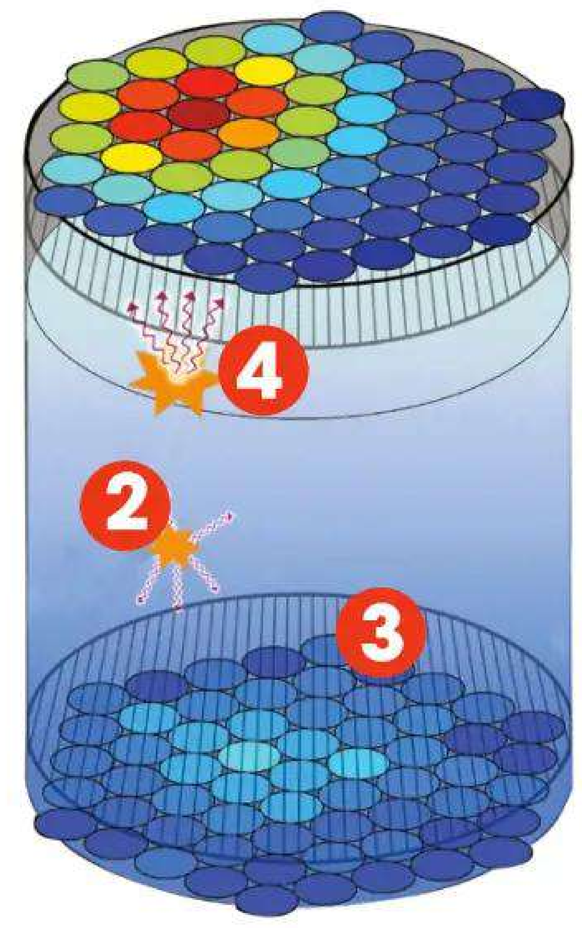
The Large Underground Xenon (LUX) experiment is buried deep beneath South Dakota, now home to the Sanford Underground Laboratory. It consists of a large tank filled with 370 kilograms (816 pounds) of liquid xenon and works on the assumption that dark matter is made of weakly interacting massive particles, or WIMPs. Occasionally a WIMP should interact with a xenon atom, emitting electrons and ultraviolet light. LUX has been working since 2012 but so far has found no evidence for WIMPs, but this has allowed scientists to constrain their models to narrow the search.

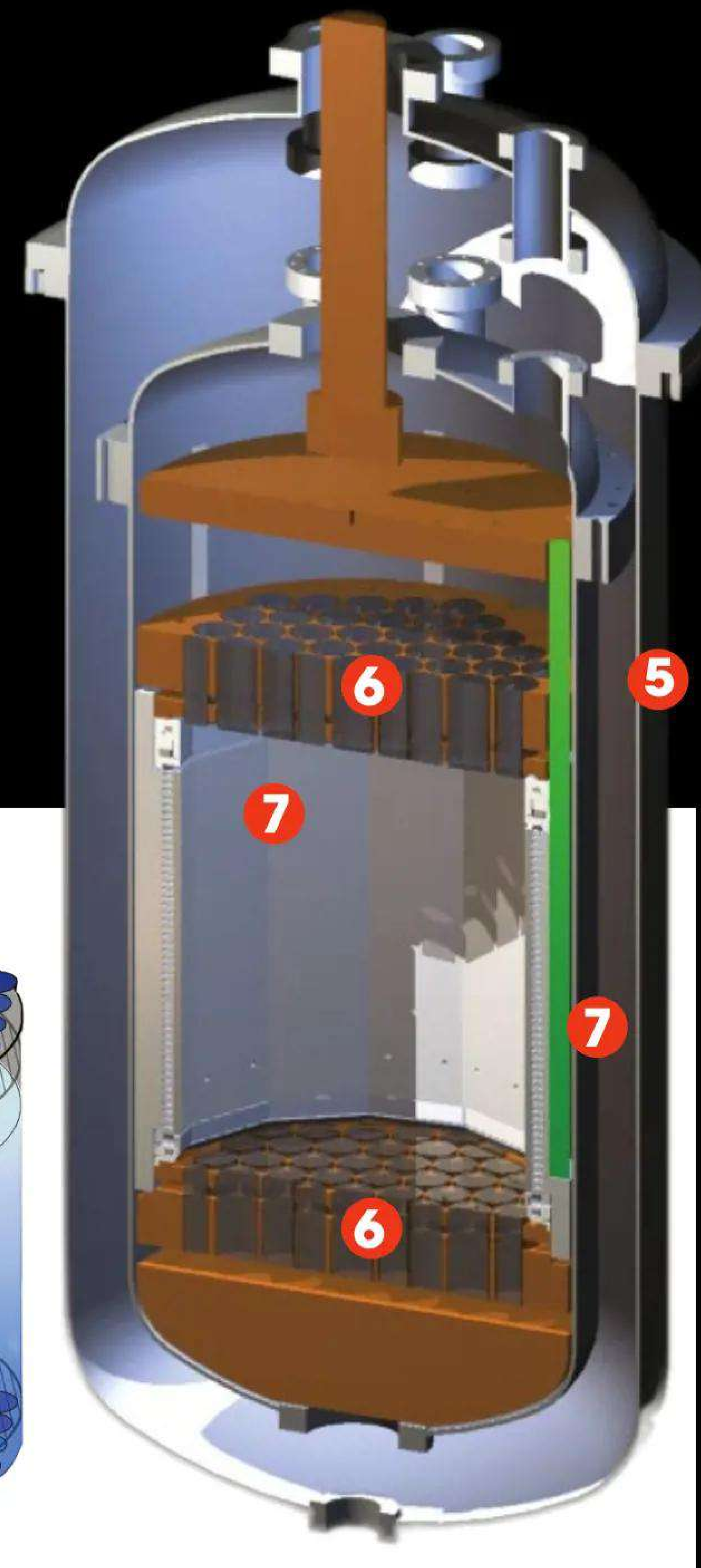


Going underground

The Large Underground Xenon experiment is searching for dark matter in South Dakota







1 Liquid xenon
Some theories on dark matter suggest it could occasionally interact with atoms such as xenon.

2 Interaction
During the interaction, the xenon atoms recoil and an electron and a UV photon are emitted.

3 Ultraviolet
At a wavelength of 175nm, the ultraviolet photons are detected by sets of photomultiplier tubes.

4 Electrons
The electrons drift to the top of the tank where they are stimulated by an electric field to emit detected light.

5 Tank
The experiment is shielded inside an 8x6m (26.2x19.7ft) water tank that keeps out external radiation.

6 Light sensors
Two sets of photomultiplier tubes, 122 in all, are arranged at the top and bottom of the experiment.

7 Cryostat
The experiment has to be kept cold for xenon to remain liquid, cooling LUX to -120°C (-184°F).

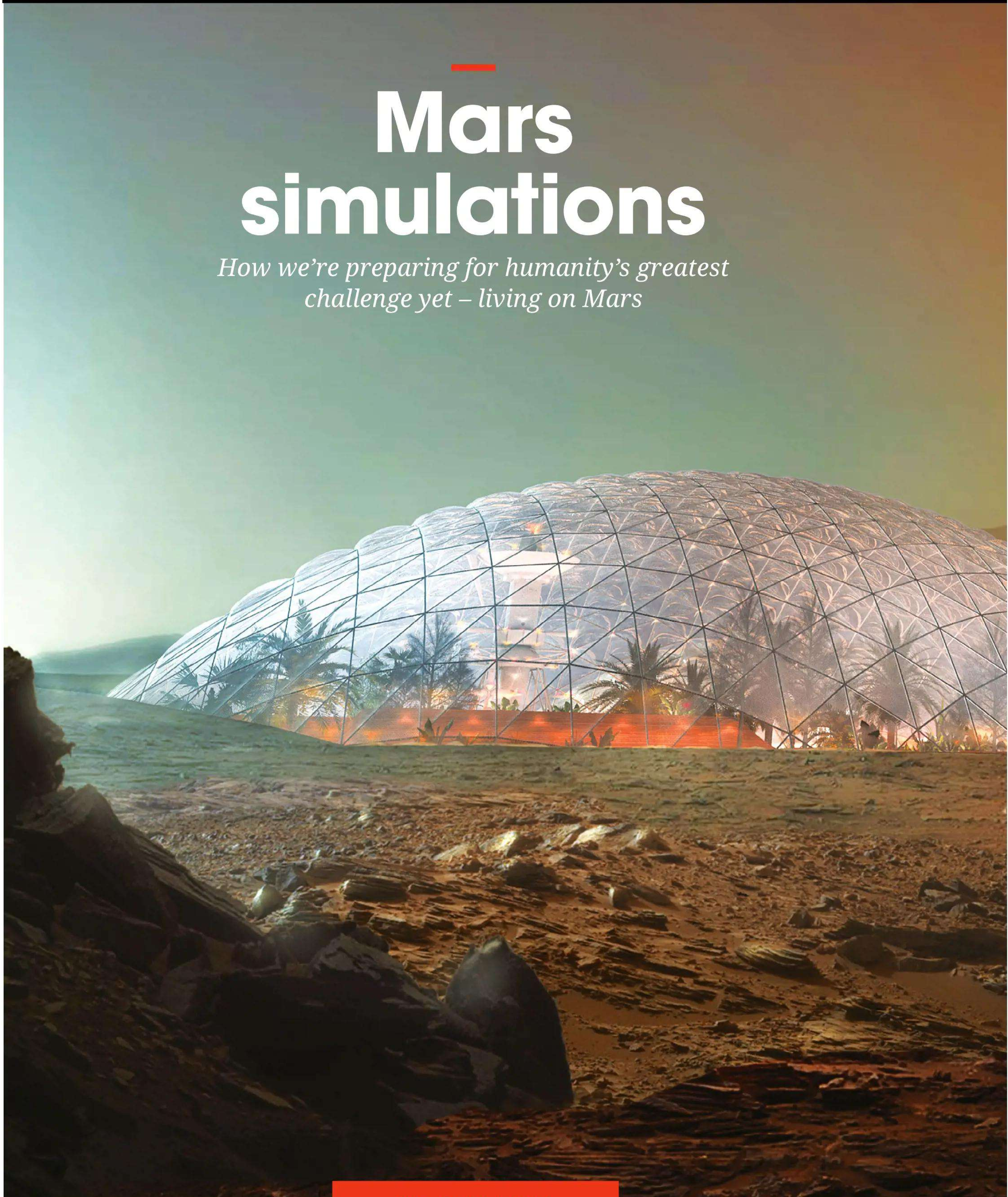
contaminate the results. Experiments such as the Cryogenic Dark Matter Search in a mine in Minnesota in the United States have freezing cold detectors, cooled to fractions of a degree above absolute zero, search for the heat produced when a WIMP collides with an atom of a substance such as germanium. Another experiment, the Large Underground Xenon (LUX) dark matter detector is located 1.6 kilometres (one mile) under the Black Hills of South Dakota, USA. It contains tanks of liquid xenon for WIMPS to interact with, the interaction producing signature radiation that can be detected.

The hunt for dark matter also takes place in space. On rare occasions dark matter particles could collide and annihilate each other, releasing an antimatter particle known as a positron (the anti-particle to the negatively charged electron), but because there is so much dark matter in space, and it's particularly densely packed close to the centre of the galaxy, there should be a steady stream of positrons. Now an experiment on the International Space Station, known as the Alpha Magnetic Spectrometer, may have actually detected some of these positrons.

Some astronomers think we shouldn't be searching for dark matter at all, as they don't believe it even exists. Concerned that dark matter theory adds more complexity to the universe than necessary, they argue that the gravitational effects we infer as being down to dark matter suggest we simply need to tweak the laws of gravity instead. As a result, dark matter now has a theoretical rival called Modified Newtonian Dynamics, or MOND. Will the theory of dark matter be usurped? As time goes on, the chances of experiments detecting dark matter will increase, so it may soon come into the light.

Mars simulations

How we're preparing for humanity's greatest challenge yet – living on Mars



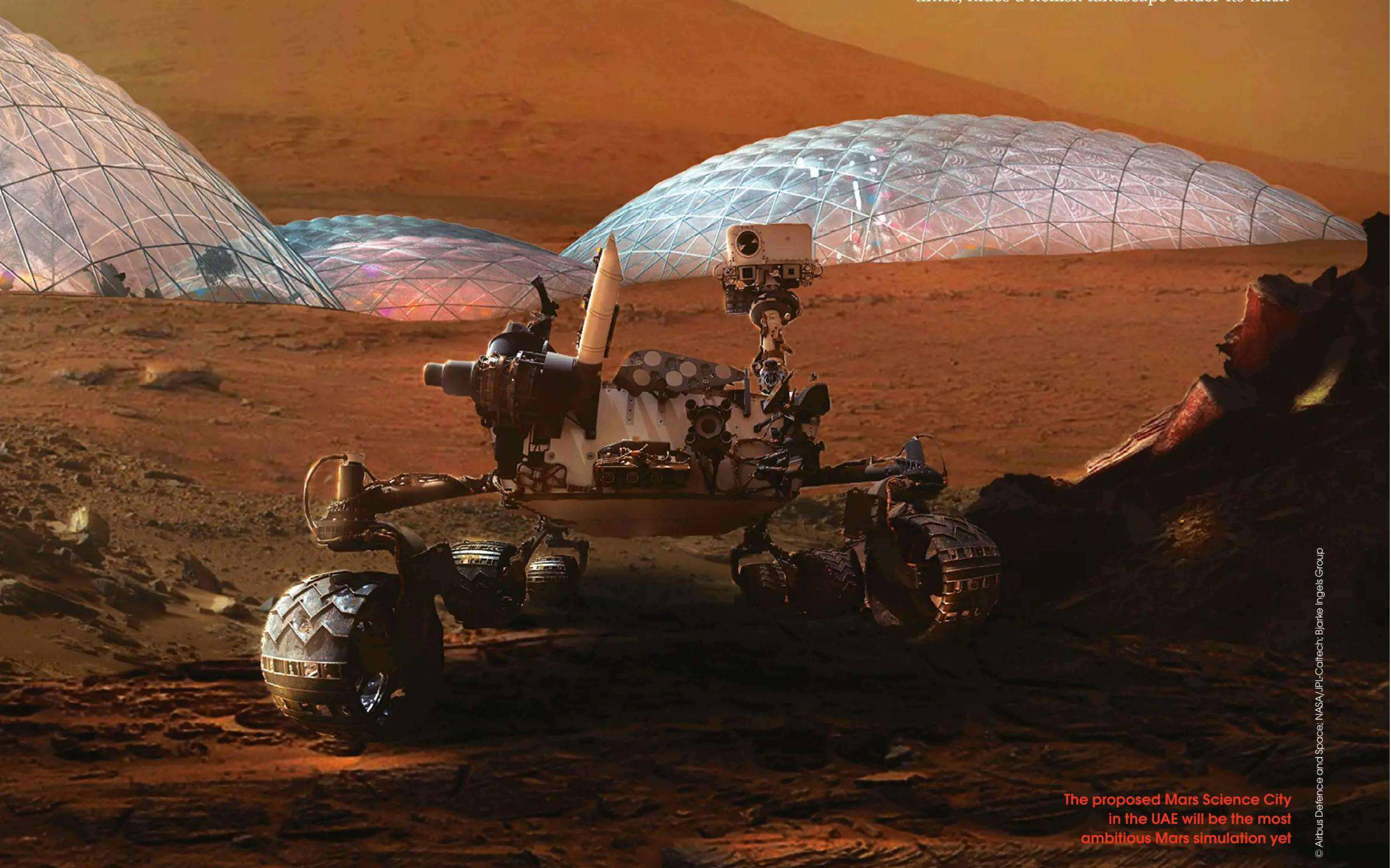
THE EXPANDING UNIVERSE

There is no shortage of dreamers with their eyes on Mars. From SpaceX CEO Elon Musk's proposal to settle a million people there within a century, to NASA's more modest attempts to land crews on the surface and return to Earth in the 2030s, the Red Planet is the 21st century's promised land. But while getting humans there will be difficult enough, surviving on the surface will be no less taxing. That's why for two decades scientists have been practising for future Mars missions by conducting simulated missions right here on Earth, ensuring we're ready for some of the challenges that will face us.

"Simulation missions will prepare us for the challenges of Mars"

While we may one day colonise Mars, our initial forays will be lengthy return trips that push the limits of the human body. Astronauts will have to cope with a travel time of up to eight months in each direction, locked away on a spacecraft drifting through space. Owing to the orbits of our planets, which only align for a trip between the two roughly every 26 months, they'll also need to spend months on the surface conducting research before they can even consider coming home. Astronauts will need to be physically prepared for prolonged conditions in lower gravity and, just as importantly, psychologically ready for the intense isolation such missions will entail.

Mars and Earth, at first glance, could not seem more different. Our own planet contains everything we need to survive, from a breathable atmosphere to food aplenty and, crucially, water. Mars, on the other hand, is deadly. Here, a thin atmosphere does little to protect the surface from harsh levels of radiation. The poisonous atmosphere composed almost entirely of carbon dioxide does little to entice visitors, and a seemingly barren surface, devoid of any obvious liquid water, leaves the planet without one of life's greatest necessities. Yet Mars is also the closest planet to Earth we could feasibly explore with our own two feet. Venus, despite being slightly closer at times, hides a hellish landscape under its thick



The proposed Mars Science City in the UAE will be the most ambitious Mars simulation yet

atmosphere where sulphuric acid rains down and temperatures are hot enough to melt lead.

Mercury, our Solar System's other rocky planet, is so close to the Sun that travelling there is extremely difficult – and even if you did, the lack of an atmosphere renders its surface all but inhospitable. While some of the icy moons of the gas giants further out may look appealing, they are places only our descendants will contemplate visiting. Mars, upon closer inspection, starts to look quite enticing.

Thus it has become the focus of many of our near-future exploration proposals, a rocky world that may well see humans walk its surface in the coming decades. While our two planets are not much alike, we do know a lot about the Red Planet thanks to numerous orbiters and rovers that have been sent there. As such, we have been able to conduct simulation missions right here on Earth to prepare astronauts for what it might be like on Mars.

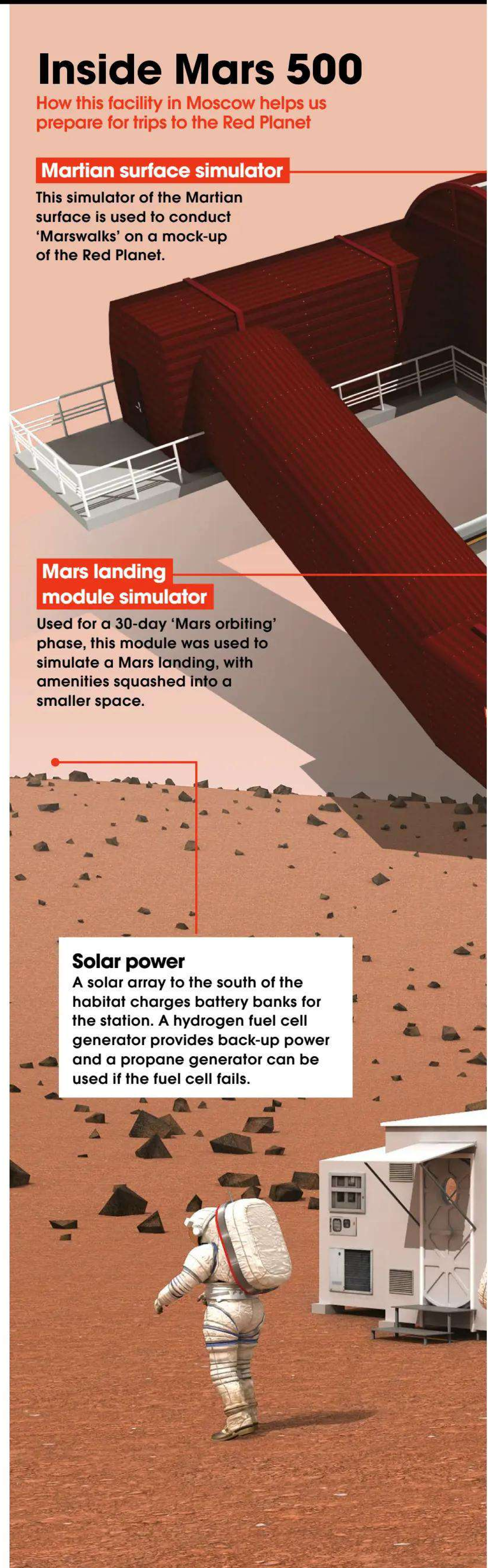
Over the last two decades numerous such missions have taken place. The goal of these has been mostly to house small crews inside habitats on Earth. Here, so-called 'Marstronauts' practise Red Planet missions, living in isolation for up to a year at a time with limited communications with an outside team to simulate mission control on Earth. These habitats contain everything they need to survive, including facilities to grow plants, exercise machines, kitchens and bathrooms. One of the earliest attempts was the Flashline Mars Arctic Research Station (FMARS), established by the Mars Society in Nunavut, Canada, in 2000. Since then, 14 crews of about six people each have spent a month or so in the station at a time, practising techniques such as aerial surveys that might be useful on future missions. The Mars Society also runs the Mars Desert Research Station (MDRS) in Utah, USA, which houses crews for a couple of weeks. Here, the crews have conducted experiments that include practising techniques for detecting life on Mars.

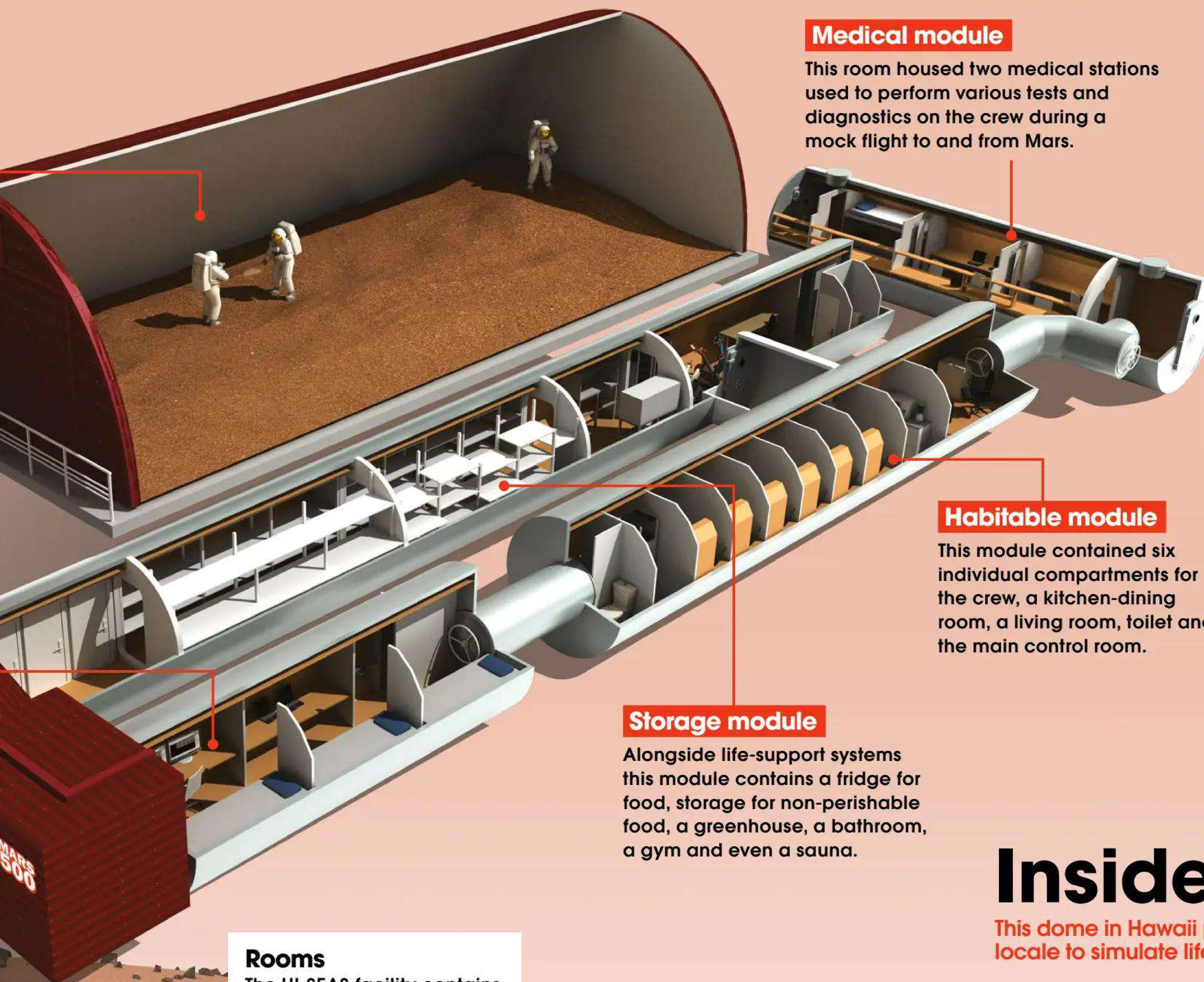

Future Mars astronauts will need to be able to conduct research on the surface

The goals of these projects and others is to provide an environment that is as close to Mars as possible, making areas like the deserts of Utah particularly useful. While we can't replicate the conditions exactly, we can get pretty close. At some facilities astronauts even go outside on practice 'Marswalks', seeing how they would cope exploring the surface of Mars, where, despite gravity being about one-third that of Earth, conditions can seem surprisingly Earth-like at times.

Many of the missions not only test out new technologies, but also the psychological aspect of living in isolation for so long. In June 2010, a joint Russian-European-Chinese mission called Mars 500 took place, which housed a crew of six inside a mock spacecraft for 520 days. This was


The crew outside HI-SEAS perform a mock Marswalk

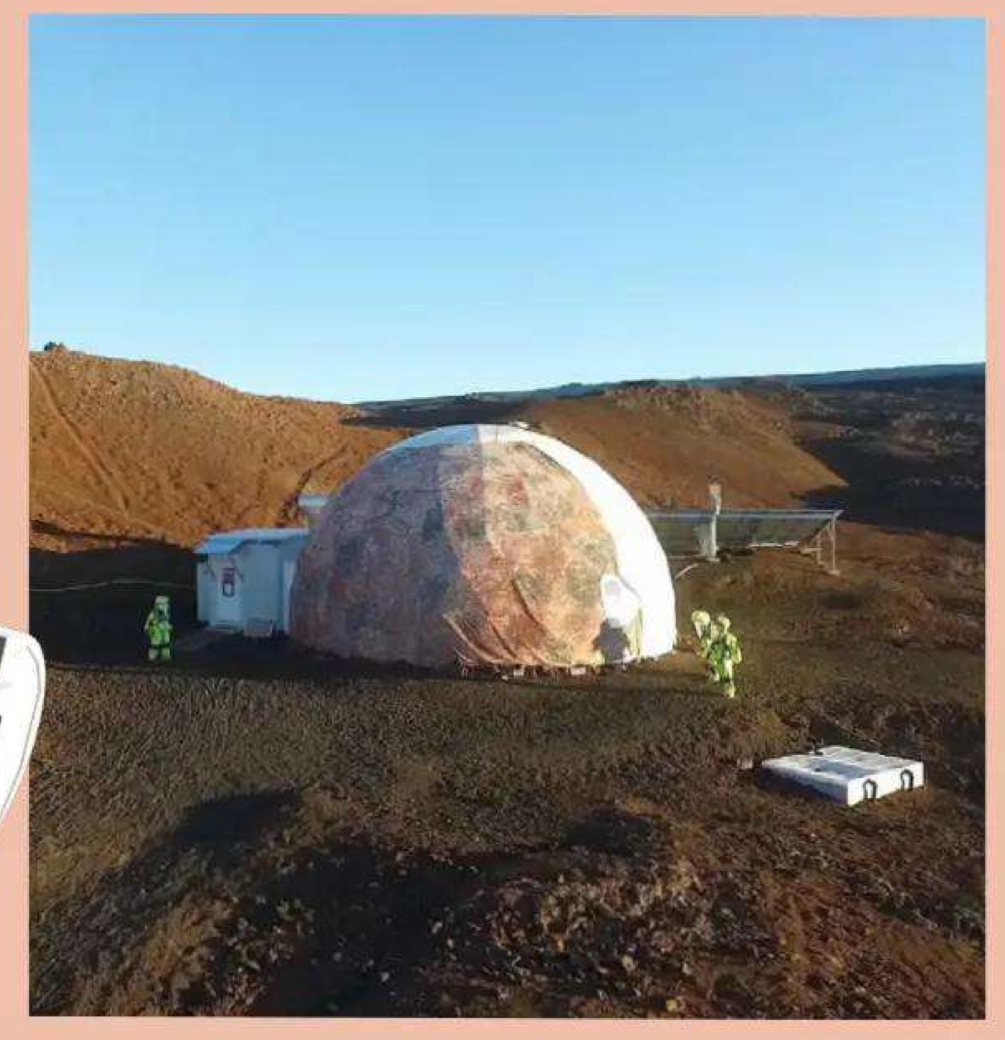




Medical module
This room housed two medical stations used to perform various tests and diagnostics on the crew during a mock flight to and from Mars.

Habitable module
This module contained six individual compartments for the crew, a kitchen-dining room, a living room, toilet and the main control room.

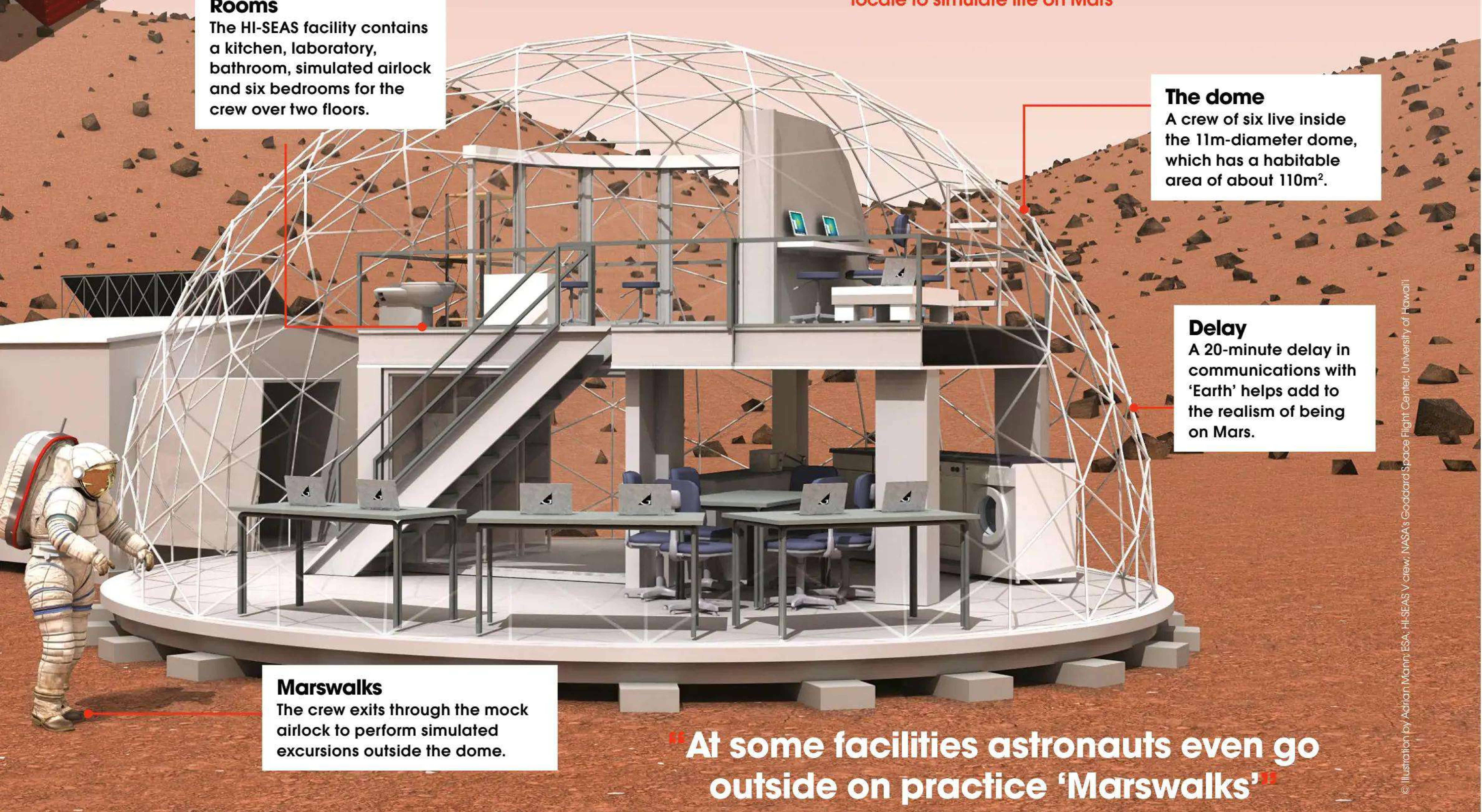
Storage module
Alongside life-support systems this module contains a fridge for food, storage for non-perishable food, a greenhouse, a bathroom, a gym and even a sauna.



The HI-SEAS dome is located on Mauna Loa in Hawaii

Inside HI-SEAS

This dome in Hawaii provides a unique locale to simulate life on Mars



Rooms
The HI-SEAS facility contains a kitchen, laboratory, bathroom, simulated airlock and six bedrooms for the crew over two floors.

The dome
A crew of six live inside the 11m-diameter dome, which has a habitable area of about 110m².

Delay
A 20-minute delay in communications with 'Earth' helps add to the realism of being on Mars.

Marswalks
The crew exits through the mock airlock to perform simulated excursions outside the dome.

> "At some facilities astronauts even go outside on practice 'Marswalks'"

NASA's deep-sea NEEMO facility helps prepare for life in isolation

intended to simulate the time it would take to travel to Mars and back, with the crew also performing a mock-up 'Mars landing' when they 'arrived' at the planet during the mission.

NASA has also been testing the limits of human psychology, having conducted a year-long mission on the International Space Station (ISS) from March 2015 to March 2016. American astronaut Scott Kelly, in partnership with Russian cosmonaut Mikhail Kornienko, spent twice as long on the orbiting laboratory as typical US missions in order to see how they coped with the stresses of prolonged spaceflight.

However, it's not just humans that have to prepare for Mars. The European Space Agency (ESA) has Mars Yards here on Earth, where they can test out rovers on simulated Martian terrain to see how they will cope. ESA is planning to send a rover called ExoMars to the Red Planet in 2022, so they are currently running it through various tests here on Earth to see if it can handle steering over or around rocks. They also test out its instruments to make sure they'll be able to analyse the surface of a planet at least 54.6 million kilometres away.

Over in Hawaii, there's another human Mars analogue mission called HI-SEAS (Hawaii Space Exploration Analog and Simulation) run by Cornell University and the University of Hawaii at Manoa in partnership with NASA. This facility is shaped like a giant dome, which might be closer in appearance to future Mars habitats – a dome or spherical shape holds up much better under the lower pressure on Mars than a rigid square or rectangle. Teams at HI-SEAS live in confined conditions and have to contend with a 20-minute communication delay, just as future Marstronauts would expect, among other challenges during their mission.

At the Concordia research station in Antarctica, there's a different sort of Mars simulation experiment taking place, where up to 16 people live very much in isolation for up to a year at a time. This French-Italian facility, run by the ESA, endures four months of continual darkness every year, while its freezing conditions have earned it the name 'White Mars'. The endless dark, white environment provides an excellent analogue for what it might be like to live in isolation on the Red Planet.

All these projects highlight one thing: there is a continued clamour for Mars, and the desire to send humans to our neighbouring planet is only growing. With new spacecraft being developed that make the dream more of a reality, research from simulation missions could prove vital in preparing humans for the isolation that initial missions will require. While we may one day have vast colonies there housing thousands of people, initial missions will be lonely, with crews of a handful of people spending months on a barren planet far from Earth. To prepare for those missions, well, there's no place like home.

Making it on Mars

We'll need more than food and shelter to survive off-planet. Danish architecture firm Bjarke Ingels Group have identified eight major factors will be vital for future Mars missions – the graphic below illustrates how they are all connected

Recreation
All work and no play makes Jack a dull boy. Future astronauts or citizens on Mars will need some form of entertainment, with proposals including cinemas or even rock climbing.

Nature
Astronauts will need to perfect growing techniques in order to be as self-sustainable as possible on Mars. This includes finding ways to grow plants in lower light conditions.

Food
Regular cargo missions from Earth might be in short supply while on Mars, not to mention very expensive. Astronauts will need to be capable of growing their own food.

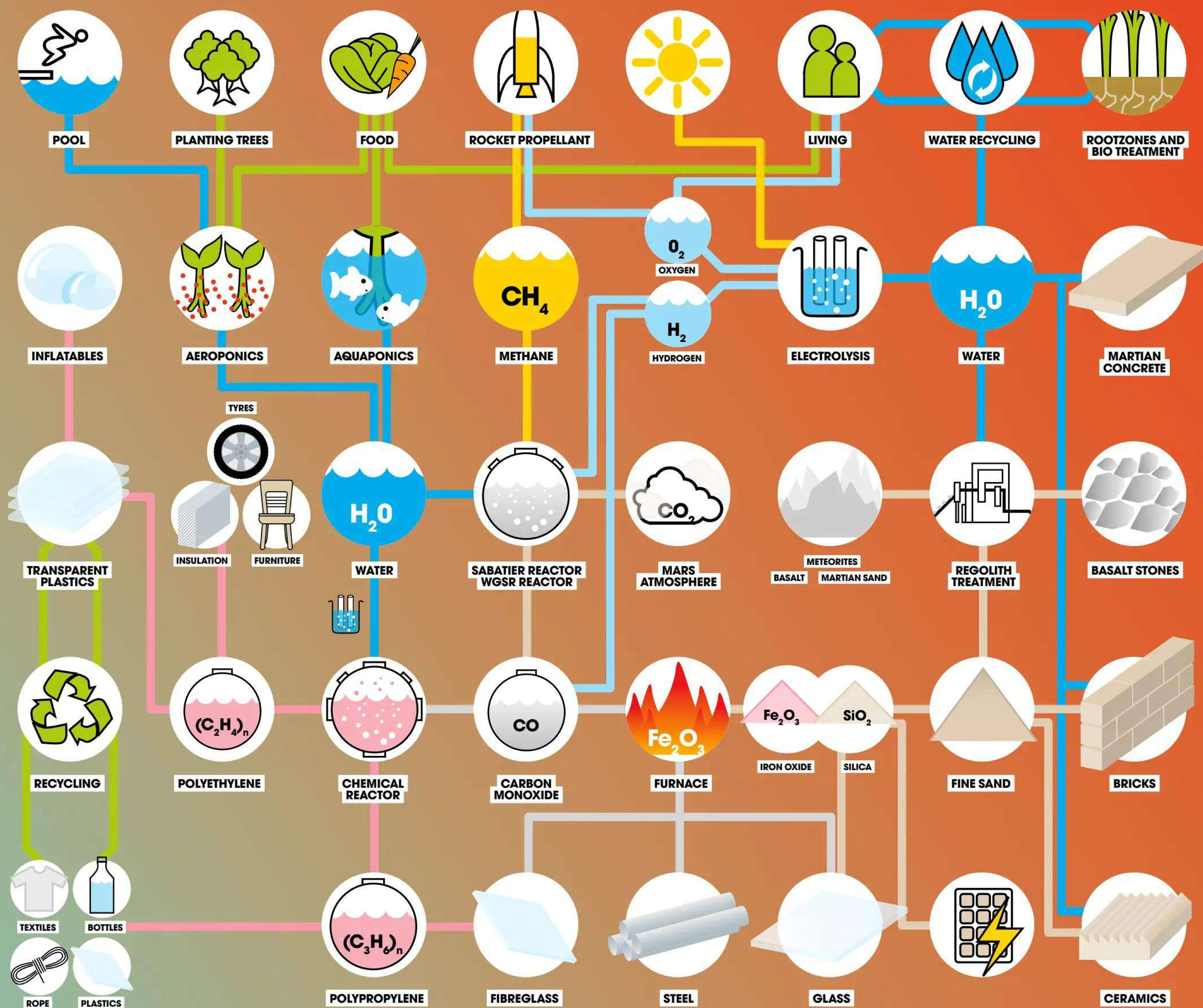
Transport
Mars missions will need to find ways to make fuel, possibly by turning the abundant quantities of carbon dioxide into methane, so they can leave the surface when necessary.

Energy
The sunlight that Mars receives is less than half as intense as it is on Earth, meaning that solar panels will need to make better use of the available energy to fully sustain a colony.

Climate
Humans cannot survive out in the open on Mars, so they'll need to live inside pressurised habitats that can mimic the pressure, temperatures and climate found back on Earth.

Water
Mars has water locked away in ice at its poles and under its surface. It's hoped that we might be able to use this for future missions, alongside efficient water recycling systems.

Waste
Any missions to Mars will need to ensure they do not contaminate the surface with Earth-based microbes, which could lead to a false detection of life in the future.



The secrets of light speed

& the fastest phenomena in space

High-velocity particles can tell us a lot about the way the universe works – but can we ever overcome the ultimate speed limit?

For a few months in early 2012, the scientific world held its breath as researchers raced to establish whether one of the greatest tenets of modern physics was under threat. The panic was triggered by reports from the Gran Sasso National Laboratory, beneath Italy's Apennine Mountains, which appeared to show bursts of neutrinos (tiny, near-massless subatomic particles), fired from a particle accelerator at CERN on the Swiss/French border, travelling faster than the speed of light.

According to more than a century of established physics, the speed of light in a vacuum – 299,792.458 kilometres (186,282.397 miles) per second – is the ultimate speed limit of the universe. No object with mass can reach this speed for very good reasons outlined in the work of Albert Einstein; as they get close, travelling at so-called 'relativistic' speeds, the strange effects predicted by Einstein's theory of special relativity take effect, including time slowing down, distances contracting and mass increasing (making it ever-more difficult to accelerate). Only massless photons of light and other electromagnetic radiation can reach the speed of light itself.

Sadly for those anticipating a revolution in physics sources, rigorous checking at the Gran Sasso laboratory eventually identified errors in the timing of the neutrino bursts, confirming they had, in fact, not exceeded the speed of light: for the moment at least, the status quo prevails.

But 'superfast' doesn't always have to threaten the fundamental laws of physics – objects moving far faster than we would expect, even if not at relativistic speeds, can still present us with intriguing puzzles to solve.

Looked at from this perspective, our universe is full of superfast phenomena – from weird particles that get within a trillionth of a per cent of light speed itself, to planets, stars and even man-made space probes moving far, far faster than a speeding bullet.

Special relativity and the ultimate speed limit

Albert Einstein developed his theory of special relativity in order to resolve a crisis in physics during the late 19th century. As methods for measuring the speed of light got more and more accurate, it became clear that it did not behave like other phenomena – its speed was always the same, regardless of the relative motions of source and observer.

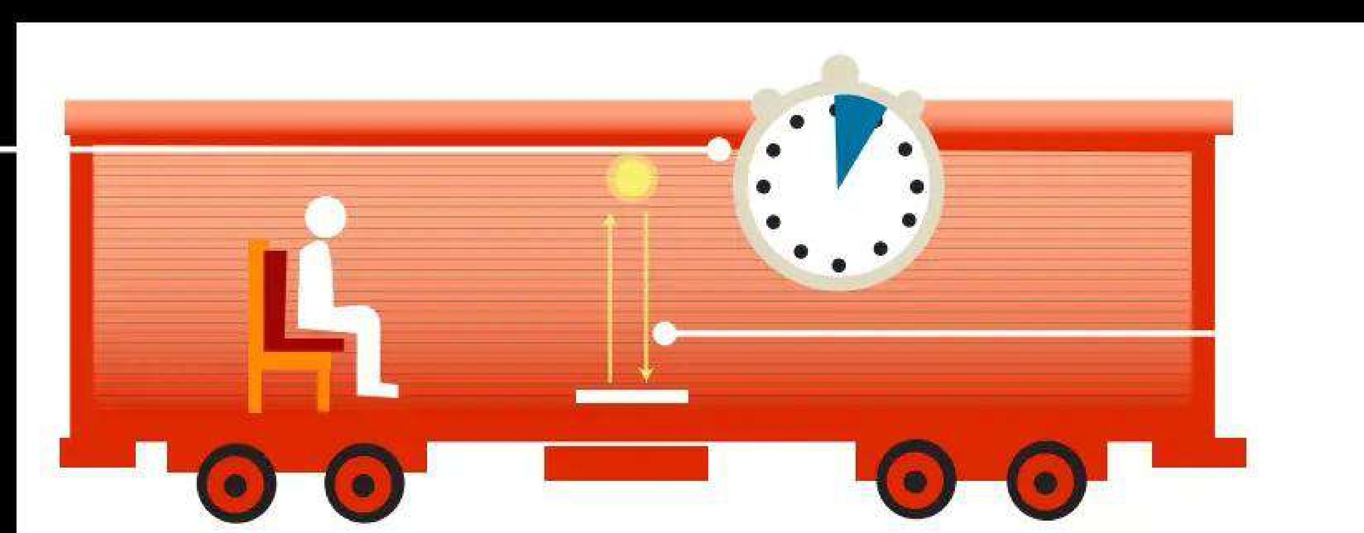
Physicists tried various tricks to get around the problem, but Einstein was the only person who dared to tackle it head on. He rewrote the laws of physics from the ground up based on two simple principles: a fixed speed of light and the 'principle of special relativity' – that the laws of physics should appear the same for all observers in 'inertial reference frames' (situations and viewpoints not involving acceleration or deceleration).

Einstein showed that objects moving at 'relativistic' speeds (superfast speeds comparable to that of light) must experience distortions in their apparent mass, length and even the flow of time (as seen from the point of view of an outside observer). These distortions become infinite when an object attempts to move at the speed of light itself, convincing Einstein that light speed is the ultimate speed limit. Einstein's theory now has more than a century of experimental observations to back it up.

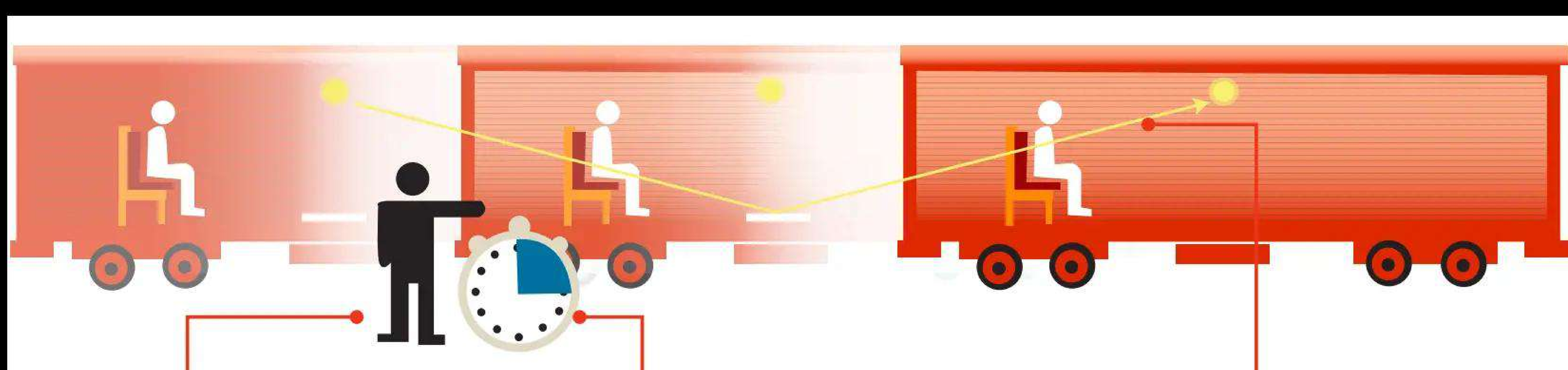
Why is it all relative?

Seen from outside, objects moving close to light speed undergo a contraction in their length and a slowing in the flow of time

1. Measuring time
Light travels at a fixed speed, so a person in a sealed train carriage could use the interval taken for light to bounce from ceiling to floor and back as a measure of time.



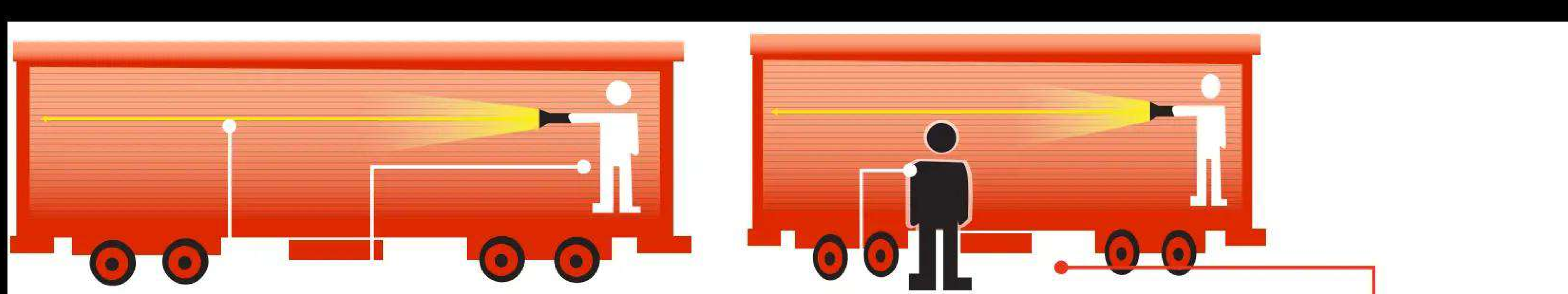
2. Inertial reference frame
Assuming the carriage is not accelerating or decelerating, then according to the man on the train, the light takes the shortest, vertical path up and down.



3. Stationary observer
Now consider an external observer standing on the station platform and watching the train passing at high speed...

5. Relativity of time
Therefore the stationary observer and the man on the train measure different times for the same event. The faster the train moves, the longer the interval becomes as measured from outside – an effect known as time dilation.

4. Longer path
The observer on the platform sees light travel a much longer, diagonal path from ceiling to floor and back. Since light travels at a fixed speed, they measure a longer time interval.



6. Measuring length
The fixed speed of light also means we can use the time it takes to travel between objects as a measure of distance.

7. Inertial reference frame
The man on the train measures the length of his carriage by timing how long a light ray takes to travel along its length.

8. Outside observer
The outside observer sees the end of the carriage moving toward the light ray, so the path the light takes is shorter.

9. Lorentz contraction
The two people disagree on the length of the train carriage; the outside observer sees what is known as a 'Lorentz contraction' that increases with the speed of the train.

Quick-fire blazar jets

Blazars are distant 'active galaxies' with the supermassive black holes in their cores feeding voraciously on matter from their surroundings. Gas and dust spiralling into the black hole forms a superhot disc that from a distance looks like a rapidly changing, starlike point of light, while a powerful magnetic field spits out jets of particles perpendicular to the disc at relativistic speeds. In other types of active galaxy, we see this jet at an angle, but in blazars, the axis of the jets points more or less straight toward Earth. This creates an illusion of faster-than-light motion – material moving along the jet is almost able to keep pace with the radiation it emits, so emissions from a knot of material emitted near the blazar's core arrive at Earth just shortly after those emitted by the same material much farther out, giving the impression that the knot may be moving at many times the speed of light, but this is an illusion.

Hunting for blazars

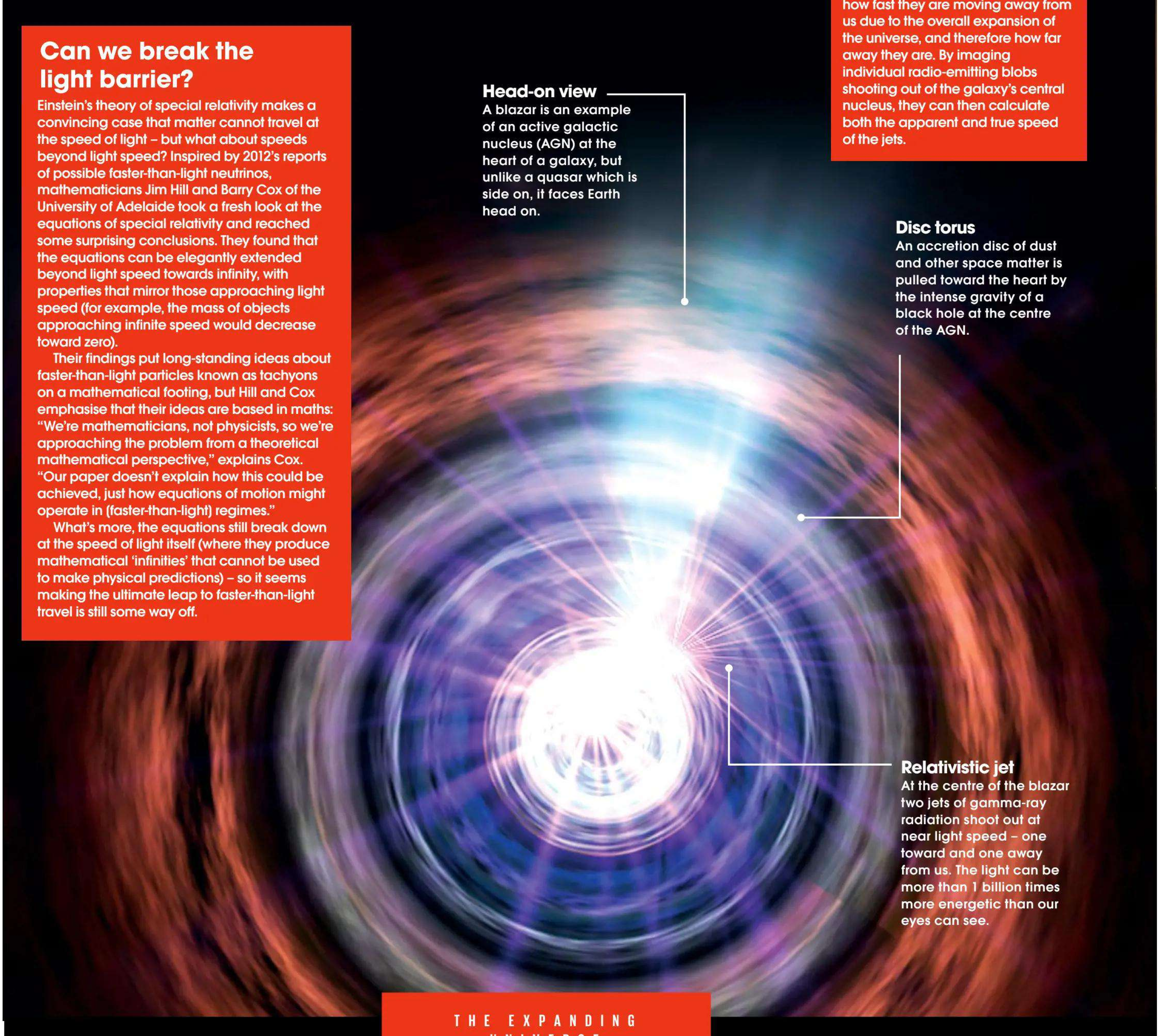
The first blazars to be discovered were initially thought to be unusual variable stars – it was only in 1968 that astronomers discovered that they emit radio waves and appeared to be embedded within faint elliptical 'host galaxies' – characteristics similar to quasars, another type of active galaxy nucleus (AGN). Today, astronomers estimate the distance to blazars by measuring the 'red shift' in light from the host galaxies – an indication of how fast they are moving away from us due to the overall expansion of the universe, and therefore how far away they are. By imaging individual radio-emitting blobs shooting out of the galaxy's central nucleus, they can then calculate both the apparent and true speed of the jets.

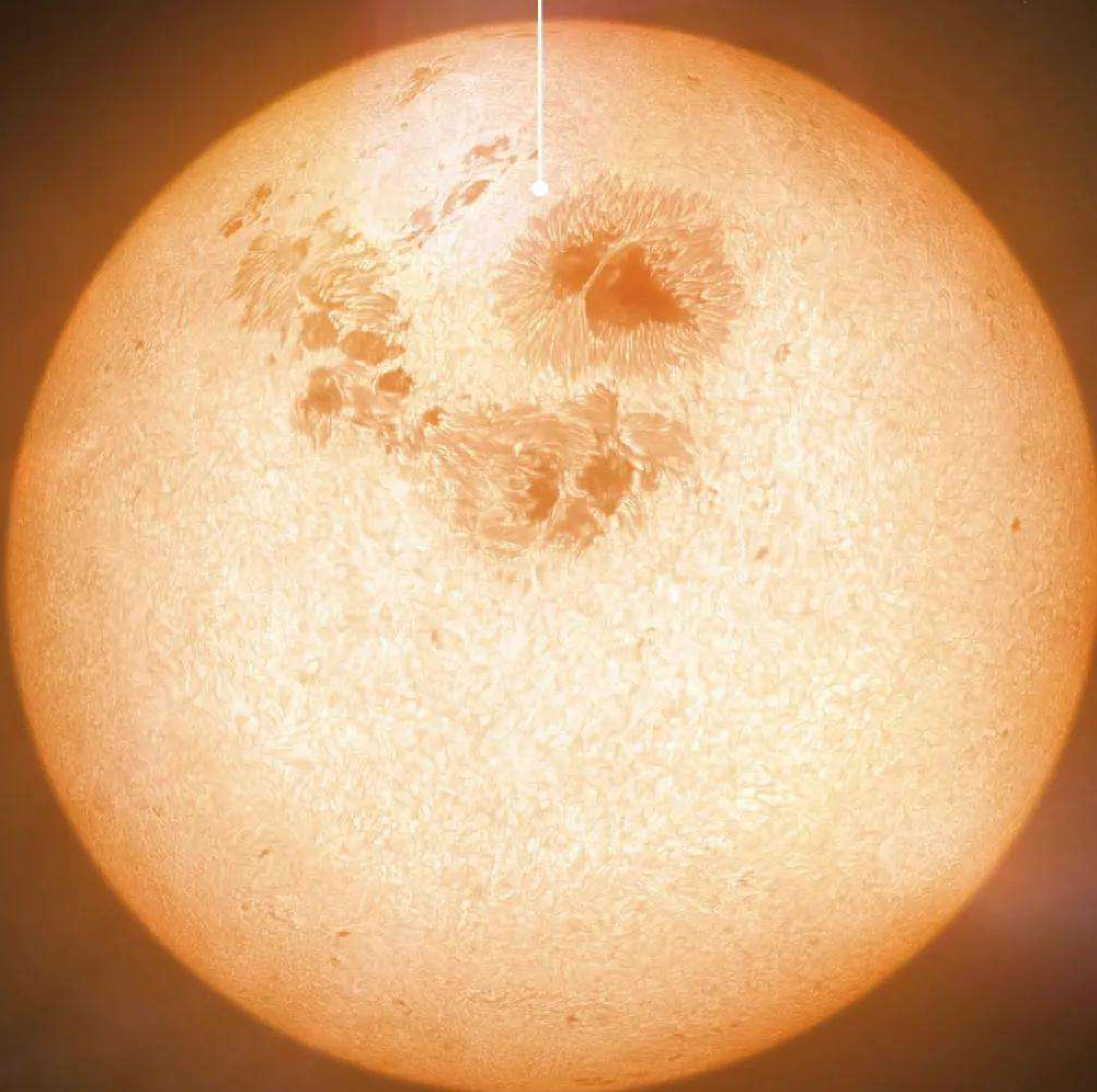
Can we break the light barrier?

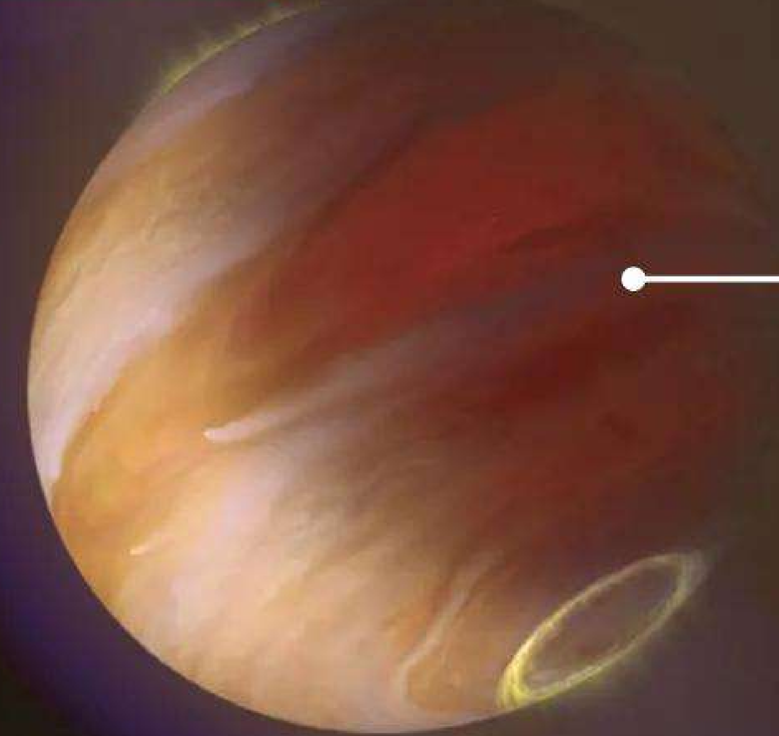
Einstein's theory of special relativity makes a convincing case that matter cannot travel at the speed of light – but what about speeds beyond light speed? Inspired by 2012's reports of possible faster-than-light neutrinos, mathematicians Jim Hill and Barry Cox of the University of Adelaide took a fresh look at the equations of special relativity and reached some surprising conclusions. They found that the equations can be elegantly extended beyond light speed towards infinity, with properties that mirror those approaching light speed (for example, the mass of objects approaching infinite speed would decrease toward zero).

Their findings put long-standing ideas about faster-than-light particles known as tachyons on a mathematical footing, but Hill and Cox emphasise that their ideas are based in maths: "We're mathematicians, not physicists, so we're approaching the problem from a theoretical mathematical perspective," explains Cox. "Our paper doesn't explain how this could be achieved, just how equations of motion might operate in (faster-than-light) regimes."

What's more, the equations still break down at the speed of light itself (where they produce mathematical 'infinities' that cannot be used to make physical predictions) – so it seems making the ultimate leap to faster-than-light travel is still some way off.







Fastest planets in space

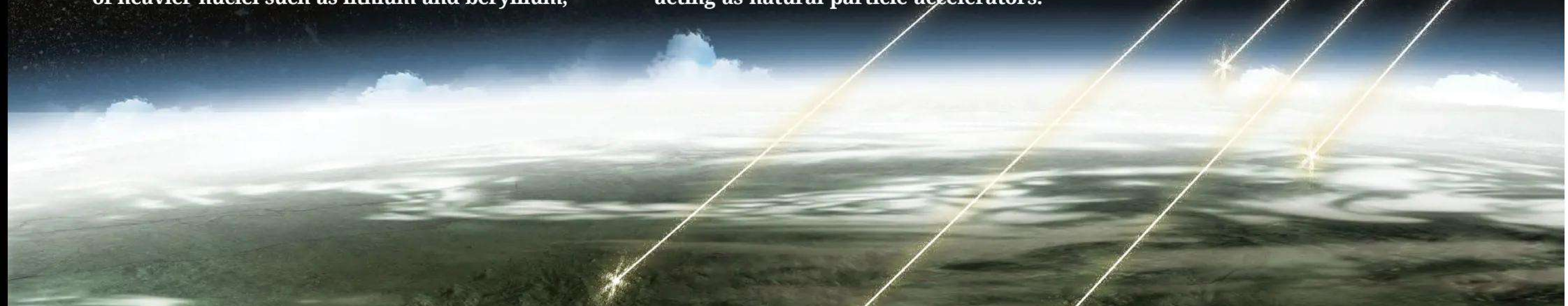
The laws of gravity mean the closer a planet orbits its star, the faster it must move in its orbit. Our home world is moving along its orbit at an average speed of 29.8 kilometres (18.5 miles) per second, while Mercury has an even higher top speed of 59 kilometres (37 miles) per second. But these speeds are nothing compared to the fastest-moving planets in our galaxy – so-called ultra-short period planets, or USPPs, which orbit their stars in just a few hours. The fastest-known planet of this type, called Kepler-70b, is thought to be the exposed solid core of a planet that was once like Jupiter, and orbits its star at an average of 272 kilometres (169 miles) per second. No planet could ever form in such an extreme orbit, so astronomers believe that instead, these gas giants originated much farther out in their solar systems, and then spiralled inward through interacting with leftover material in clouds of planet-forming material. Some of these 'hot Jupiters' meet their doom by crashing into their parent stars. Rogue planets, kicked out of their planetary systems by the same process that creates hypervelocity stars (see over page), can also achieve great speeds.

Cosmic rays: the fastest particles

Cosmic rays are particles moving at extremely high speed through space, originating from outside our Solar System. They rarely reach the surface of Earth intact, disintegrating into showers of lighter, lower-energy particles after colliding with gases in the upper atmosphere. Nevertheless, by tracking the speed and distribution of these secondary particles (and using satellite and balloon-based detectors), astronomers can discover a surprising amount about the properties of primary cosmic rays.

Mostly atomic nuclei of hydrogen and helium – the two lightest elements – with small amounts of heavier nuclei such as lithium and beryllium, they fall into two distinct categories. Most 'normal' cosmic rays travel at speeds of around 99 per cent of the speed of light. Trillions of them bombard Earth every second and evidence suggests a significant proportion were ejected from distant supernovas.

A much rarer population of ultra-high energy cosmic rays (UHECRs), meanwhile, carry far more energy and travel at speeds a tiny fraction of a per cent below light speed itself. UHECR sources seem to lie in the same direction as distant active galaxies, and some astronomers believe they are created by fast-spinning supermassive black holes acting as natural particle accelerators.

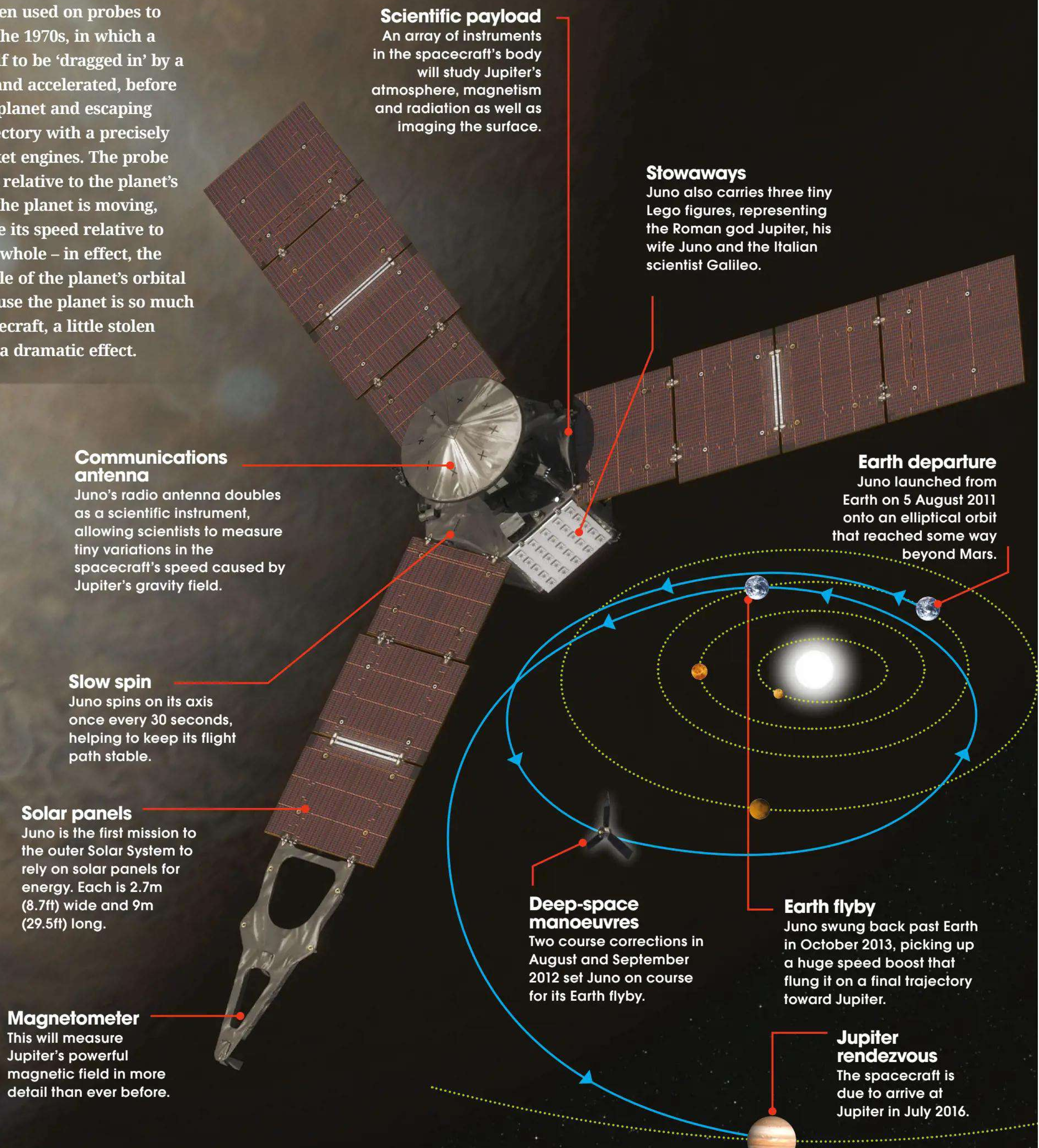


Quickest-ever spacecraft

In October 2013, the Jupiter-bound Juno spacecraft flew past Earth in a gravitational 'slingshot' manoeuvre that boosted its speed to become the fastest man-made object in the universe, shooting past us at nearly 40 kilometres (25 miles) per second relative to the Sun. Juno's slingshot made use of a technique that has been used on probes to distant planets since the 1970s, in which a spacecraft allows itself to be 'dragged in' by a planet's gravity field and accelerated, before swinging close to the planet and escaping along a different trajectory with a precisely timed burn of its rocket engines. The probe keeps the same speed relative to the planet's surface, but because the planet is moving, it can radically change its speed relative to the Solar System as a whole – in effect, the spacecraft steals a little of the planet's orbital momentum, but because the planet is so much heavier than the spacecraft, a little stolen momentum can have a dramatic effect.

Destination Jupiter

Juno's unique flight path to Jupiter will allow it to investigate unseen parts of the giant planet



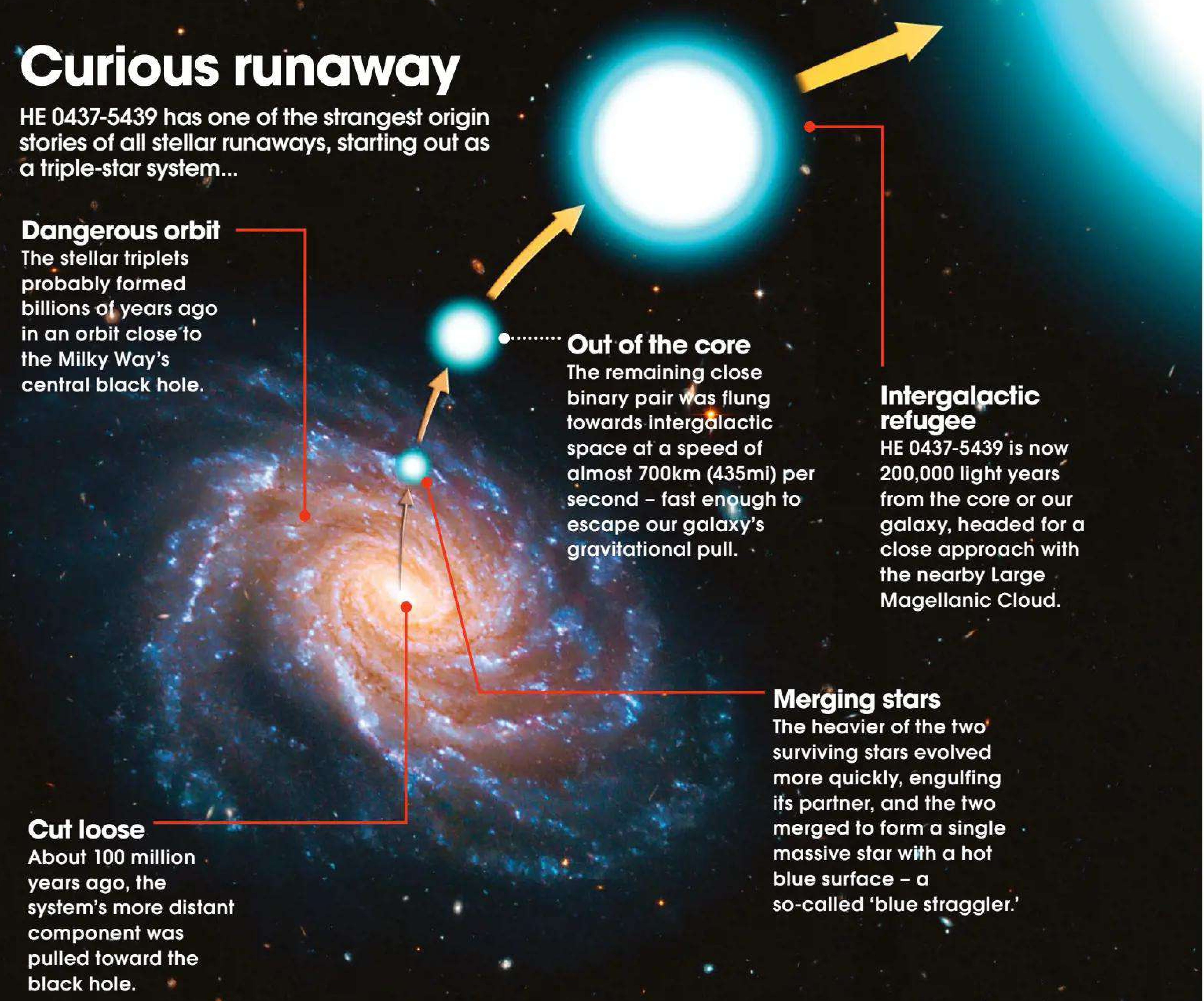
Hypervelocity stars

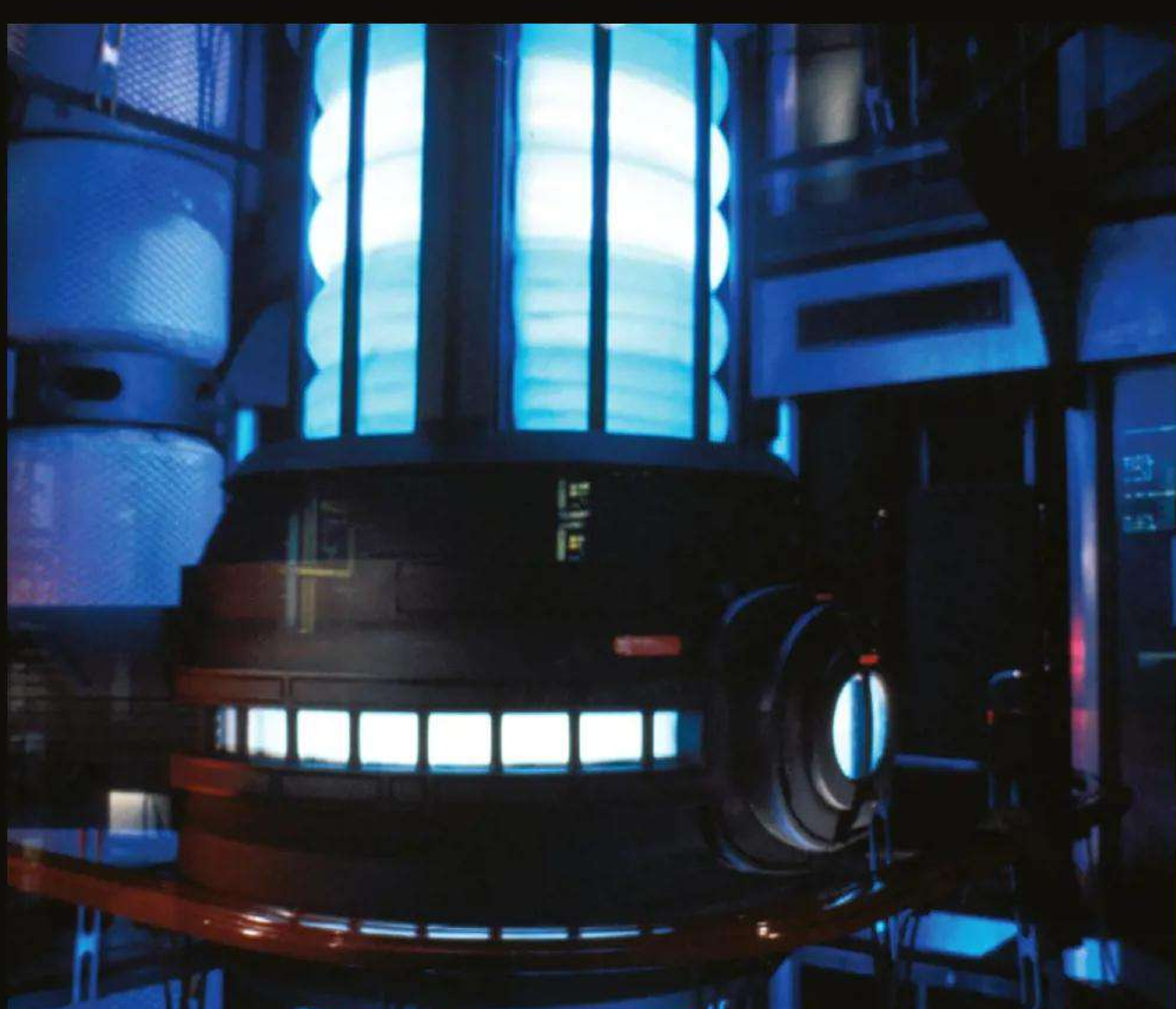
Just as planets move at different speeds depending on the distance from their parent star, so stars closer to the core of our own galaxy move faster than those farther out. Our Sun, for example (roughly halfway out across the galaxy's flattened disc), moves along its orbit at about 230 kilometres (143 miles) per second. But the space above and below the plane of our galaxy is home to high-speed runaways known as hypervelocity stars. These travel at such an immense speed that they have achieved escape velocity – moving at 700 kilometres (440 miles) per second or more; the Milky Way's gravity will never be enough to slow them down.

The paths of these hypervelocity stars can often be traced back to the centre of the Milky Way, and one popular explanation is that they can be produced when one member of a binary star system is catapulted free after a close encounter with the central black hole. However, not all hypervelocity stars come from this region, so there may be several mechanisms at work. Another theory is that hypervelocity stars have been 'cut loose' from tightly bound binary systems after their more massive partners have destroyed themselves in supernova explosions.

Curious runaway

HE 0437-5439 has one of the strangest origin stories of all stellar runaways, starting out as a triple-star system...





Warp factor: fact or fiction?

Einstein's theory of special relativity suggests that it's impossible to move across space faster than the speed of light (or at least, to pass through the light-speed barrier), but could future space pioneers find ways to overcome this problem? One option would be to make use of the time dilation effect; time would flow more slowly for the crew on board a spacecraft that is moving at relativistic speeds, perhaps allowing them to travel across many light years in what, for them, would seem like only a few months.

But Einstein's general theory of relativity, which demonstrates that space-time is a four-dimensional 'manifold' that can be warped and distorted, offers another alternative – the 'warp drive'. First outlined in 1994 by Mexican physicist Miguel Alcubierre, such a device would involve moving a 'bubble' of normal space across great distances by compressing the region of space-time ahead of it and expanding the region behind it. A spacecraft inside the bubble could move at normal speeds relative to its immediate surroundings, while the bubble itself could move at faster-than-light speeds without actually breaking Einstein's rules.

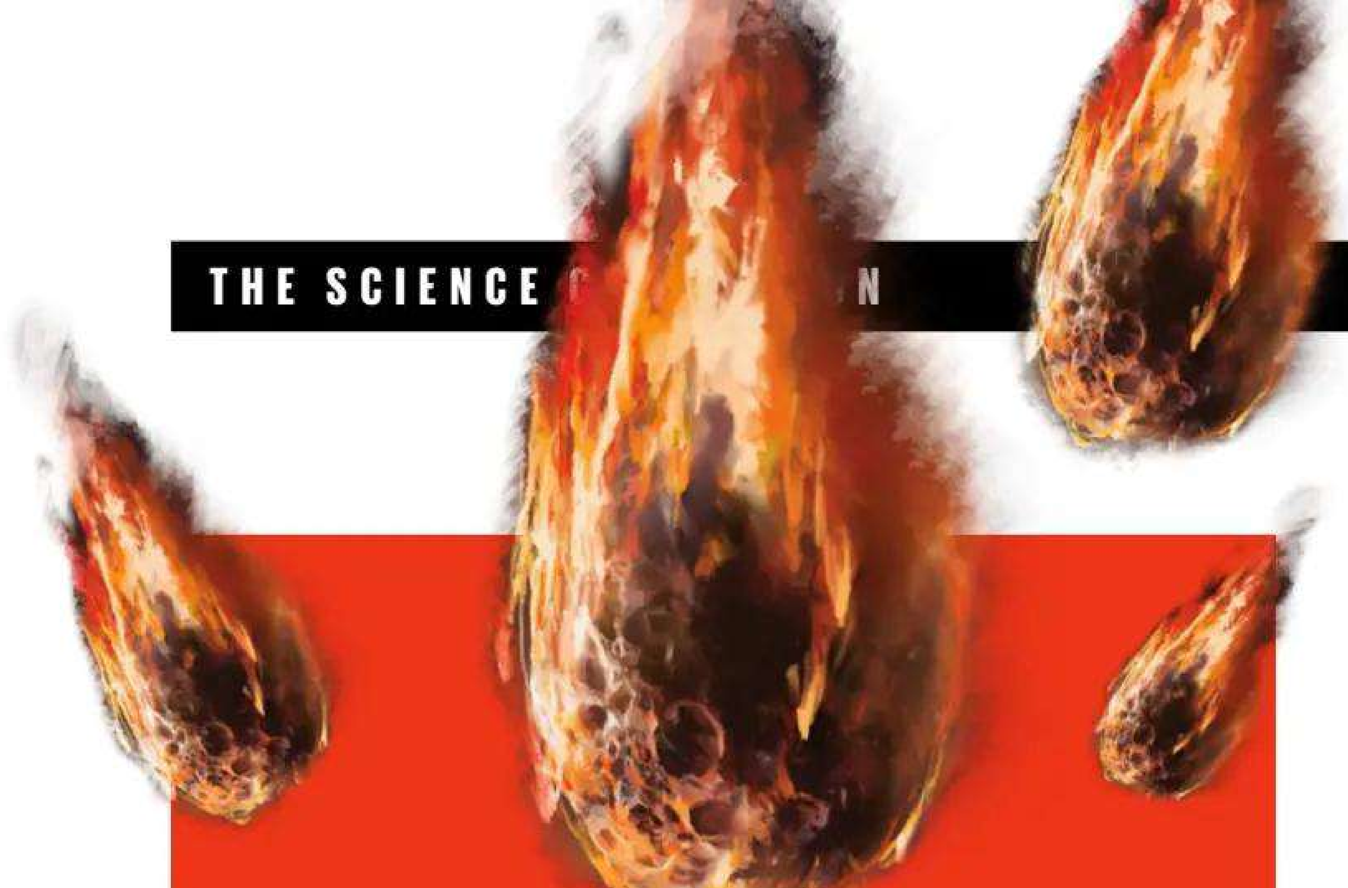
NASA scientist Harold 'Sonny' White has since shown a doughnut-shaped region of distorted space-time could radically reduce the energy needs of a warp drive, and although the practical challenges remain huge, White's team at the Johnson Space Center have begun experiments to demonstrate warp effects at a micro level, which might one day be upscaled. So there's still hope for a real-life Starship Enterprise yet...

72 hours until impact

What would we do if an asteroid was on a collision course with Earth? We reveal the plan to save humanity from extinction

Words by Libby Plummer

© Daniel Sinoca



Potential risks to planet Earth

NASA's JPL keeps a constantly updated tally of potentially hazardous asteroids using its Sentry System

(410777) 2009 FD

DETECTED BY: Spacewatch
LIKELY SIZE: 160m
WHEN IT COULD HIT: 2185-2198
One of thousands of Apollo asteroids – the largest group of near-Earth asteroids – this binary asteroid could hit Earth between 2185 and 2198.

101955 Bennu

DETECTED BY: Lincoln Near-Earth Asteroid Research (LINEAR)
LIKELY SIZE: 490m
WHEN IT COULD HIT: 2175-2199
A C-type asteroid – one that's made up largely of carbon – Bennu is the target of NASA's OSIRIS-REx asteroid sample-gathering mission.

(29075) 1950 DA

DETECTED BY: Carl A. Wirtanen, Lick Observatory
LIKELY SIZE: 1.3km
WHEN IT COULD HIT: 2880
This massive asteroid has the highest known probability of impacting Earth and would cause major devastation due to its size.

99942 Apophis

DETECTED BY: Roy Tucker, David Tholen and Fabrizio Bernardi, Kitt Peak National Observatory (KPNO)
LIKELY SIZE: 370m
WHEN IT COULD HIT: 2060-2105
Previously expected to impact as early as 2029, this asteroid set a record for the highest rating on the Torino Scale, which rates impact hazard.

A civilisation-destroying asteroid may sound like the stuff of science fiction, but the threat is very real.

These rocky fragments range in size from mere metres to hundreds of kilometres across, and while most orbit the Sun in a belt between Mars and Jupiter, the gravitational pull of planets can sometimes alter their path. If an asteroid, or a fragment of one – known as a meteoroid – makes it to the Earth's atmosphere, it usually burns up as a meteor or shooing star. However, some explode in a massive fireball, and some make it down to the Earth's surface as meteorites.

In 2013, a 10,000-ton meteor, measuring 18 metres across, hurtled into the Earth's atmosphere at 67,000 kilometres (41,600 miles) per hour before exploding 23.3 kilometres (14.4 miles) above the Russian city of Chelyabinsk. More than 1,000 people were injured as a result of the fireball, mainly by shattered glass caused by the shockwave, though luckily nobody was killed. The surprise explosion released more than 30 times the energy than that from the Hiroshima atomic bomb. To put that in perspective, the massive meteor strike that is thought to have triggered the extinction of the dinosaurs measured around ten kilometres across and released around a billion times the energy of an atomic bomb.

> **"The likelihood of an asteroid impact is really low, but the consequences can be unimaginable"**
>
> Clemens Rumpf

Before impact, the asteroid was completely undetected because it was "too small for the survey telescopes, and came at us out of the Sun", according to NASA. The potentially catastrophic incident highlighted just how important it is to monitor near Earth objects (NEOs) – comets and asteroids that have been nudged into Earth's neighbourhood.

For gaining support to develop a better surveillance network for NEOs, "Chelyabinsk helped a lot," Rüdiger Jehn, who co-manages ESA's Space Situational Awareness (SSA) and NEO team, told us. Following the strike, the European Space Agency secured vital funds to build its new 'fly-eye' telescope, which is expected to begin operations in 2019. Taking inspiration from insects which can look in multiple directions at the same time, the bug-eyed telescope splits the image into 16 sub-images to expand the field of view – up to a massive 45 square degrees.

"This is a big improvement," says Jehn, continuing, "this enables us to scan the entire sky in one night, so if something is coming, we should see it. We hope that we will be able to

Illustration of an asteroid belt around the bright star Vega based on NASA and ESA observations

spot NEOs measuring 40 metres three weeks before they approach Earth."

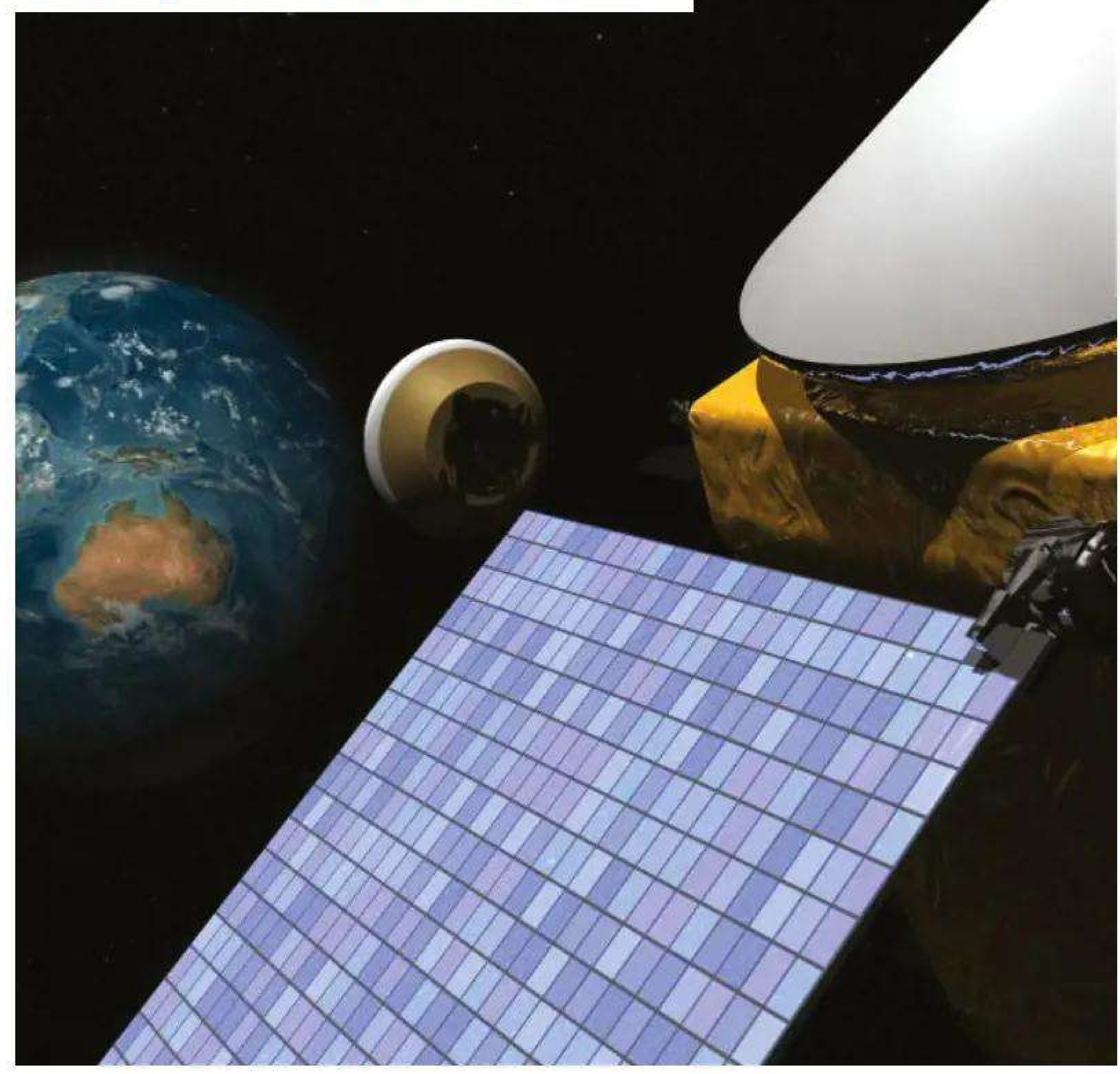
The 40-metre mark is significant because this is the approximate size of the 1908 Tunguska meteoroid that flattened 2,000 square kilometres of remote Siberian forest in the most harmful asteroid-related incident in recent history. While it's thought that this sort of size asteroid only threatens the Earth every 300 years or so, smaller ten-metre asteroids, as seen over Chelyabinsk, are more regular. The fly-eye telescope is a major step forward in safeguarding the planet from NEOs, and ESA also has guidelines in place should the worst happen.

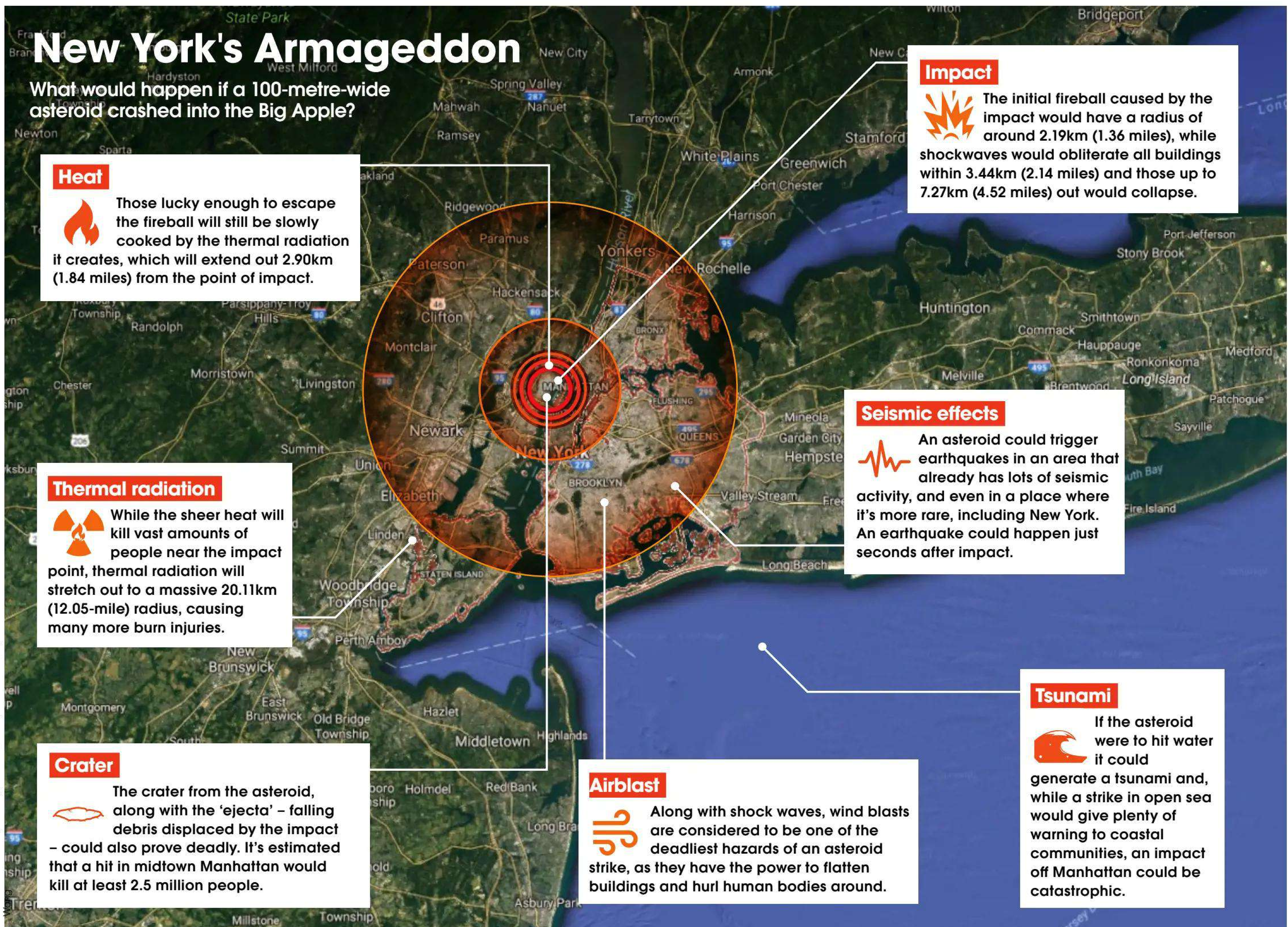
"We have a detailed information plan," says Jehn. "If we spotted an NEO three weeks away, we would not inform the public straight away as we would not want to cause a panic. The data is very sensitive and we have to be careful how we handle it. We would compare readings with NASA and tell rescue specialists and government agencies everything we know and what kind of damage to expect, and then it would be their job to decide on the right plan of action".

He estimates that there would be around two weeks' notice for the public if a 40m asteroid were on the way. While evacuation may be the answer for a larger asteroid, a smaller fragment of approximately ten metres would more likely lead to a 'shelter' strategy, similar to a hurricane warning.

The odds of a catastrophic strike on Earth are low, at least for the foreseeable future, but what would happen if a massive asteroid really did hit? The effects would include flying debris, tsunamis, lethal heat and seismic shaking, but violent winds and shock waves resulting from a spike in atmospheric pressure would be the biggest threat to human life, according to a study published in the journal Geophysical

NASA's OSIRIS-REx spacecraft will travel to a near-Earth asteroid called Bennu and bring back samples for study





In the event of an impact

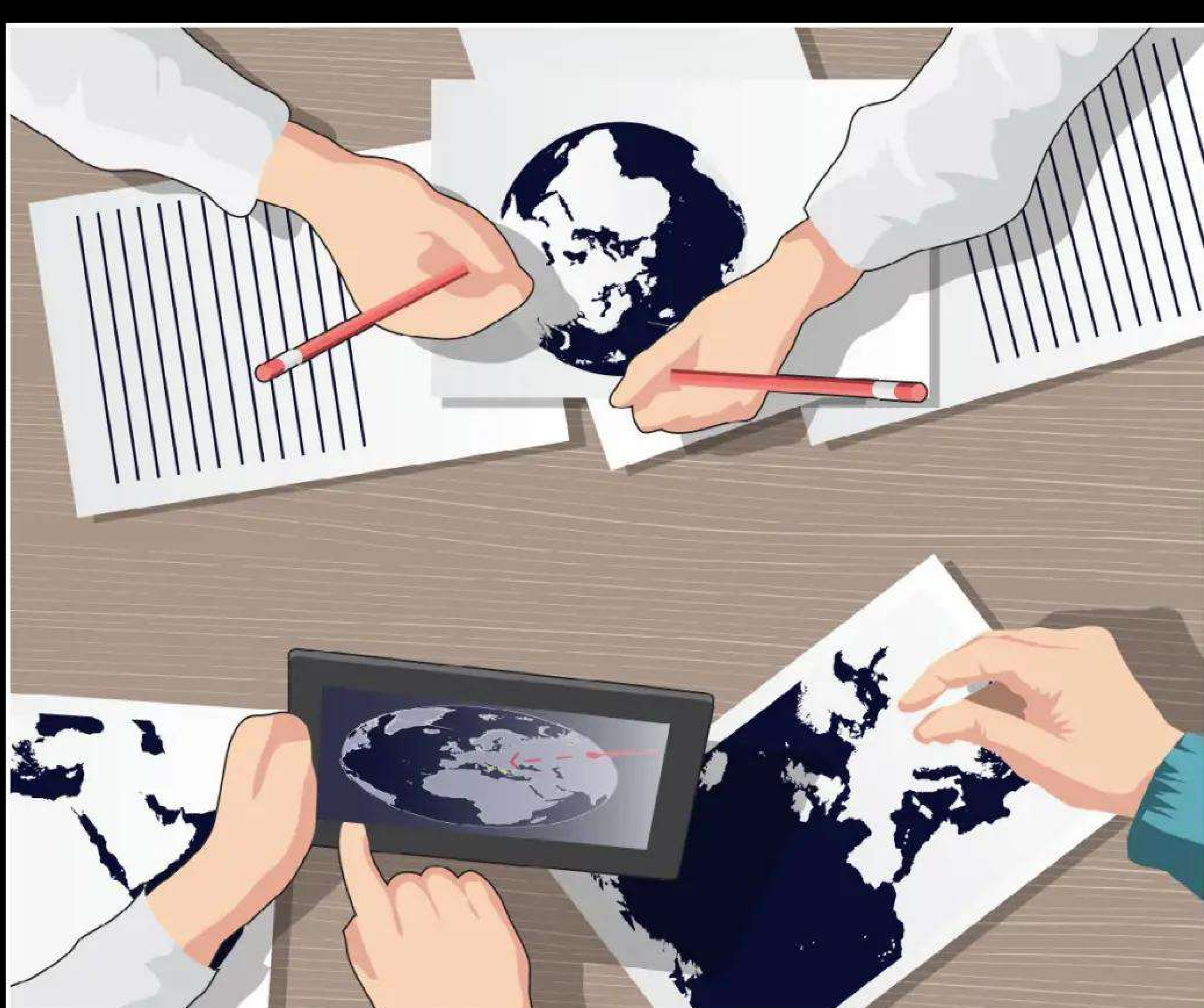
A step-by-step guide to what happens if an asteroid is hurtling towards Earth

1 Potential hazard is spotted

Survey telescopes constantly scan the sky for new NEOs. When spotted and confirmed, they are added to the list for monitoring, and if close to Earth, they get priority for closer inspection.

2 Data shared and predictions made

If one of the flagged asteroids appears to be on a course to strike Earth, the information is shared with other observatories and space agencies around the world so that they can compare data.



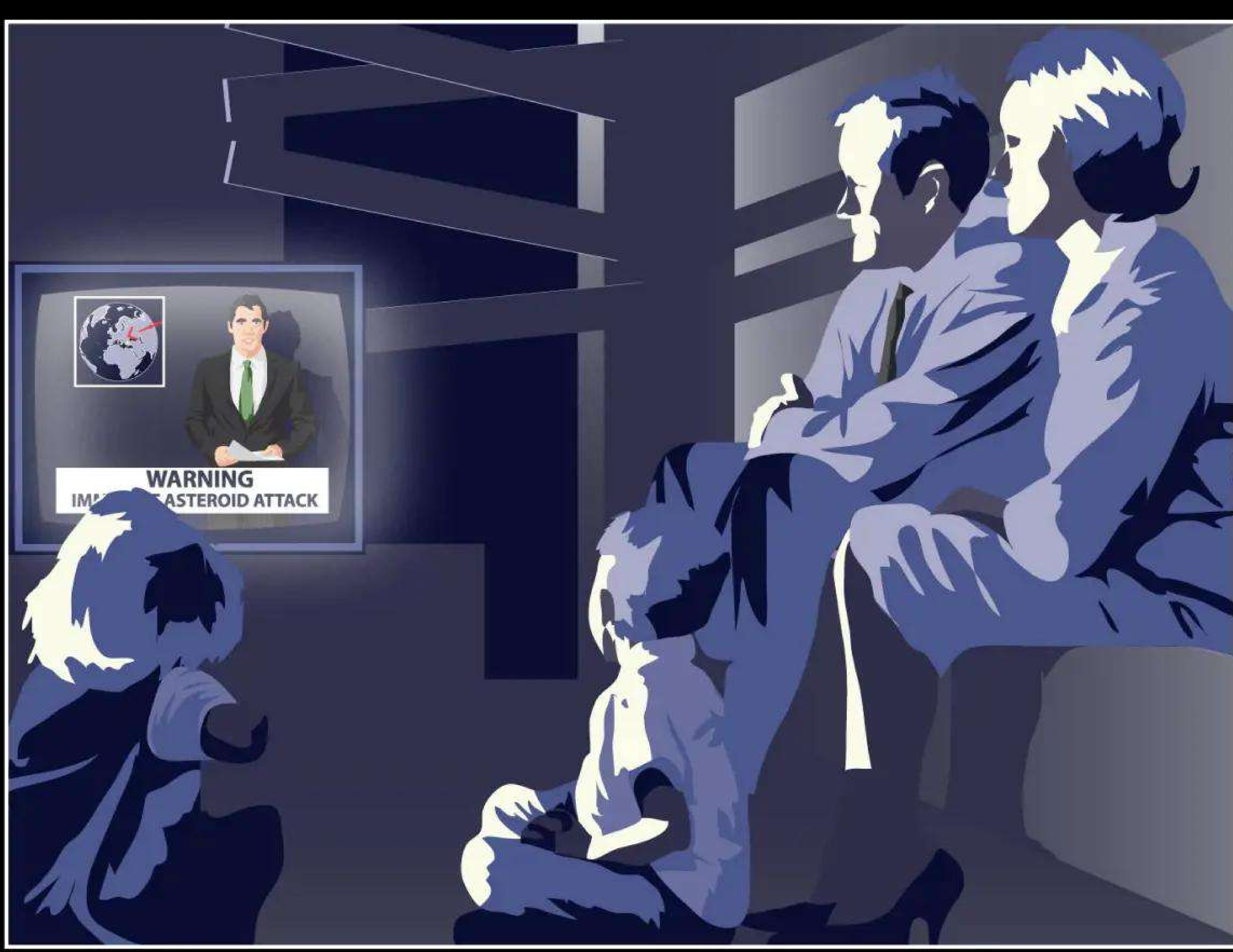
4 Rescue plans and trajectory predictions made

While keeping the information quiet from the public, initial safety plans would be put into place while the asteroid's predicted trajectory is continually updated by observatories around the world.

5 The public is informed

If the data shows the asteroid is still on course to hit, governments in the affected areas would issue safety warnings and instructions for the public around two weeks before a strike.

3 Governments and rescue agencies informed
If a strike is imminent we would have about three weeks' notice for a 40-metre asteroid. At this point, experts would inform government and rescue agencies so that initial plans can be formulated.



6 The world prepares for 72 hours until impact
While preparedness and rescue plans are still being fine-tuned, it's likely that the government would either issue warnings to take shelter for a smaller strike, or evacuate in the case of a bigger impact.

NASA's Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE) mission hunts for NEOs

"It will be incumbent upon the observatories to get a fix on the asteroid as it approaches"
Paul Chodas

Research Letters back in 2017. These two threats accounted for more than 60 per cent of deaths in a simulation carried out by researchers from the University of Southampton, who used models to plot 50,000 artificial asteroid strikes around the globe before ranking the lethality of the results.

"The likelihood of an asteroid impact is really low," says Clemens Rumpf, the lead author of its study, "but the consequences can be unimaginable." The good news is that if a potentially lethal asteroid were on a collision course with Earth, we'd know about it. NASA's Planetary Defence Coordination Office (PDCO) oversees the tracking of potentially hazardous asteroids and comets, and would assist the US government, and international agencies, in coordinating a plan if an impact was imminent.

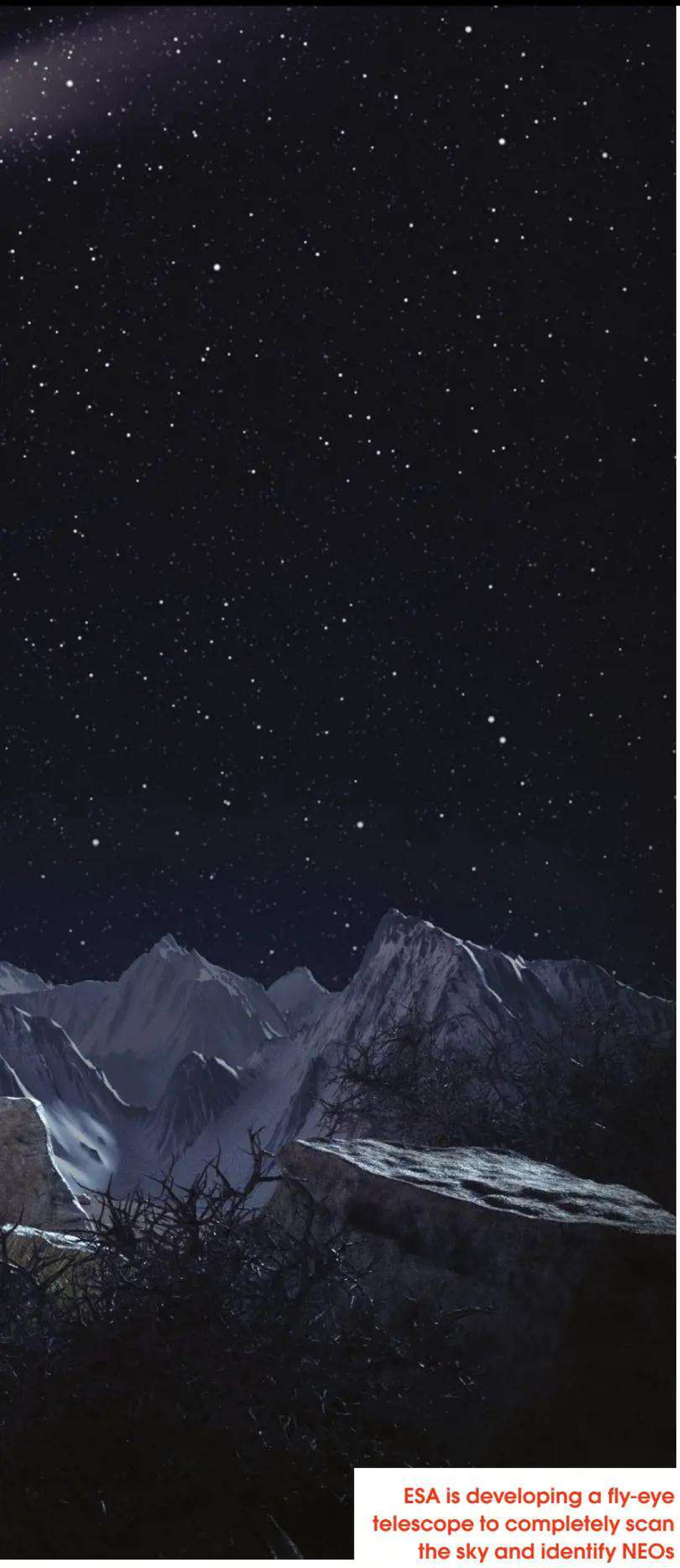
NASA has plenty of asteroid-based activity going on at the moment, including its long-serving Wide-field Infrared Survey Explorer (WISE) space telescope, which was originally launched to carry out an all-sky astronomical survey. The telescope was brought out of hibernation and reactivated as NEOWISE in 2013 to hunt down new asteroids. Meanwhile, NASA's OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer), which was launched in September 2016, is set to travel to near-Earth asteroid 101955 Bennu and bring back samples for study. As well as understanding how asteroids could impact Earth, the research could also tell us more about the formation of our Solar System, and even the origin of organic molecules that lead to the development of life as we know it.

What's more, NASA used the October flyby of a small asteroid to test its planetary defence network. Asteroid 2012 TC4 measured somewhere between ten and 30 metres across, slightly larger than the Chelyabinsk space rock, and safely passed Earth on 12 October. The tiny asteroid passed no closer than 6,760 kilometres (4,200 miles) from Earth, according to NASA's Center for Near-Earth Object Studies (CNEOS). As part of a collaborative project involving numerous observatories, universities and labs, scientists worked together to nail down the precise trajectory of the asteroid as it approached Earth. "It will be incumbent upon the observatories to get a fix on the asteroid as it approaches, and work together to obtain follow-up observations that make more refined asteroid orbit determinations possible," said Paul Chodas, manager of CNEOS, beforehand.

CNEOS is already involved in computing precise orbits for NEOs, and the flyby helped it to pinpoint any potential asteroid strikes in future. Some of its calculations are already used in simulation exercises, such as the bi-annual Planetary Defence Conference, which brings together experts from around the globe to discuss and run through hypothetical astroid-strike scenarios to develop response plans.

In recent years, governments around the world have been taking the threat posed by asteroids increasingly seriously. In 2017, the White House released the National Near-Earth Object Preparedness Strategy – a 19-page report on what needs to be done to prepare for an impact. The strategy is the precursor to a firmer plan, which at the time of writing, has yet to materialise. NASA has also carried out a series of planning exercises with FEMA (the US government's Federal Emergency Management Agency). What's more, the United Nations-sanctioned International Asteroid Warning Network (IAWN) – an organisation that includes experts from around the world – is also in place to give plenty of warning of an imminent strike.

Also keeping a watchful eye on the skies is the newly formed Asteroid Institute. Created by planetary defence organisation the B612



ESA is developing a fly-eye telescope to completely scan the sky and identify NEOs

"That is the central issue: find them early. This is the only real way to protect the public"

Dr Ed Lu

Foundation, the Institute works with planetary scientists and engineers around the world on asteroid detection and deflection. It also aims to provide opportunities to young scientists to foster talent in this vital field for the future.

"Our goal is to create a dynamic map of the solar system showing the locations and trajectories of the millions of Near Earth Asteroids large enough to destroy a city," Dr Ed Lu, former NASA astronaut and Asteroid Institute executive director tells us.

"This is the first step in defending our planet from asteroid impacts – we must first find and track asteroids, and then compute where they are going to be in the future. The B612 Foundation has seen a dramatic increase in the collaboration of governments, public and private institutions to work on identifying asteroids far in advance, so they pose no threat to Earth," says Lu. "That is the central issue: find them early. This is the only real way to protect the public".

Awareness of the threat posed by rogue asteroids is certainly increasing, with the UN declaring 30 June – the anniversary of the 1908 Tunguska event – as 'Asteroid Day'. Aimed at boosting awareness even further, the campaign counts Apollo 9 astronaut Rusty Schweickart and rock star astrophysicist Brian May among its co-founders and is backed by more than 200 high-profile astronauts and astrophysicists, including Lord Martin Rees and Apollo 13 Commander Jim Lovell.

While the idea is to spot any hazardous asteroids before they reach Earth, what if a larger asteroid was on the way? As yet, there is no known weapon system capable of shooting down as asteroid in the minutes or hours before impact because of their sheer velocity. The good news is that if such an asteroid were to emerge we would probably have around a decade to prepare.

There are several potential defence methods, including firing a nuclear device at a planet-killing asteroid to deflect it, or using a gravity-tractor spacecraft that would fly alongside the asteroid to gradually pull it into an orbit further away from Earth. NASA is already working on DART (Double Asteroid Redirection Test) – a spacecraft that's designed to smash into an asteroid. "DART would be NASA's first mission to demonstrate what's known as the kinetic impactor technique – striking the asteroid to shift its orbit – to defend against a potential future asteroid impact," says Lindley Johnson, Planetary Defence Officer at NASA. DART could pave the way for defending against major asteroid strikes.

While emergency management policies across the globe have been refined in recent years with lessons learned from major disasters and terrorist attacks, there is still some way to go to prepare for a massive asteroid strike. But with help from international space agencies and NEO-monitoring organisations, we should be prepared when the worst happens, because it's not a matter of if an asteroid hits Earth, but when.

A cloud trail left by the Chelyabinsk asteroid after it exploded in 2013

All about the Moon

It took a walk on the Moon to reveal our natural satellite's many secrets

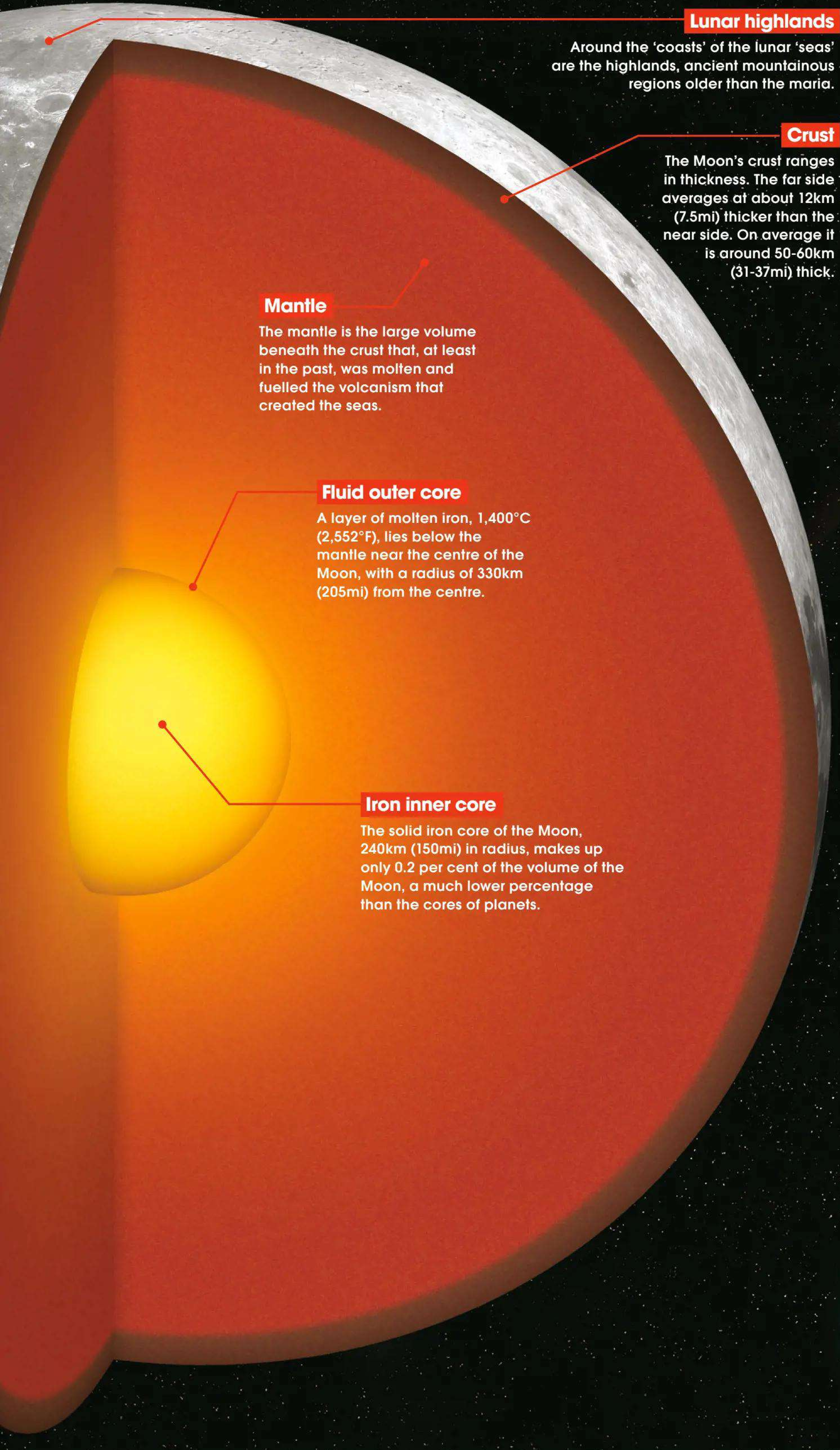
"One small step for a man, one giant leap for mankind," said the ghostly black-and-white shape of a man on live TV, broadcast to the whole world. This wasn't any ordinary man, though, and this wasn't an ordinary television broadcast, which had household upon household across the globe glued to their screens.

This was the summer of 1969 and Neil Armstrong had put spacesuit boot to soft, powdery lunar soil in a feat that had never been achieved before by anyone: he was the very first man to walk on the Moon. You might remember the Apollo 11 mission when it happened, or maybe you weren't even born, but you've managed to piece together what a momentous day it was for space exploration from newspaper cuttings, books or even from a story recounted by your relatives. Armstrong's bootprint signalled a historic change in how we see the Moon.

All throughout human history the Moon had been just a bright disc in the sky, its shape changing with a monthly regularity as different parts of it are illuminated by the Sun as it orbits Earth. Then, with the beginning of the Space Race between the USA and the Soviet Union, the Moon became a target to be reached, first by robotic probes and then by human beings. It transformed from a silvery disc into a real world, one that we have since come to understand better in part thanks to the astronauts who bravely travelled the 384,400 kilometres (238,855 miles) to its heavily cratered surface.

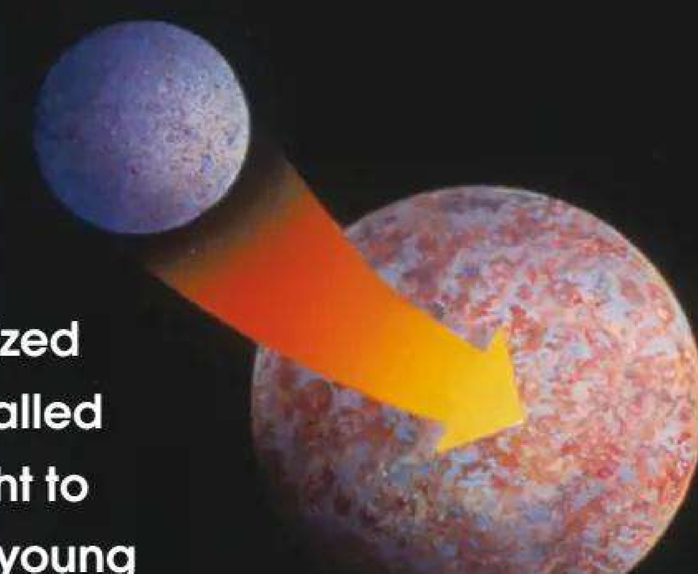
How craters are carved

Craters are the scars of impacts by comets and asteroids. Most of the craters on the Moon were formed during the Late Heavy Bombardment of 4.1-3.8 billion years ago, when an influx of asteroids invaded the inner Solar System. Craters can be dozens to hundreds of kilometres across, sport central peaks or mountains, and splash debris across the surface.



Making of the Moon

1 In for the kill



Around 4.4 billion years ago, a Mars-sized protoplanet called Theia is thought to have struck a young Earth at speed of 4km/s (2.5mi/s).

2 A planetary mix-up
The collision happened with such force that Theia's iron core sunk into Earth, while the mantles of both planets mixed together.

3 The shape of things to come
Not all of the planetary material mixed together, though – some of the mantle was tossed into orbit around Earth. These pieces would later combine to become our Moon.

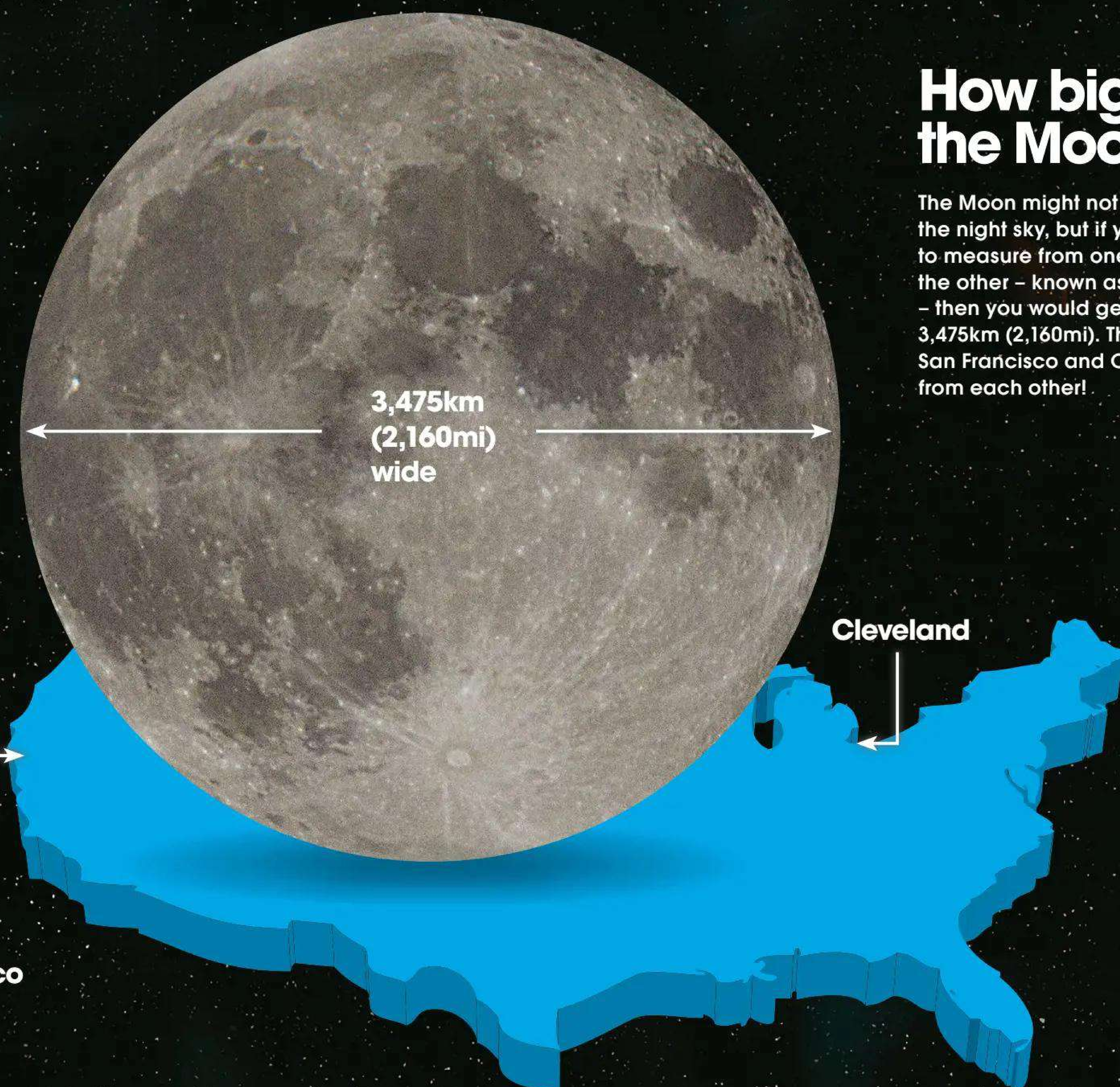
4 A companion for life
Gravity rounded off the ejected material, leaving behind the bright natural satellite that we see in the sky.

Armstrong, Apollo 11's commander, wasn't alone on the lunar surface that day. Fellow astronaut and lunar module pilot Buzz Aldrin followed him down the ladder of their lunar lander, the Eagle, and took in the alien landscape of the Sea of Tranquility. Together, they collected samples of lunar material – dust and rocks – to bring back to Earth for scientists to study and learn more about the nature of the Moon, its history and its origins. Meanwhile, third crew member and command module pilot Michael Collins stayed in lunar orbit above them, waiting for Armstrong and Aldrin to return from the surface for the trip back to Earth.

They, and the other ten astronauts to walk on the Moon after them, left footprints in the lunar dirt that will remain on the Moon for probably as long as the Moon exists. The Moon is airless; there is no wind, no erosion other than the feather touch of tiny micrometeorites that pitter-patter the surface. Scientific instruments left behind on the Moon by the Apollo astronauts have detected the seismic waves of Moonquakes, but overall the Moon today is dead and inactive. Its most active period was three to four billion years ago, when the inner Solar System was bombarded by comets and asteroids. These impacts created most of the craters we see on the Moon, and this bombardment was followed by a period of intense volcanism on the Moon. The dark patches we can see on the Moon – the seas or 'maria' – are huge frozen plains of volcanic lava that filled the largest impact sites. It is the maria that contribute the pattern of facial features of the 'Man in the Moon'.

How big is the Moon?

The Moon might not look that big in the night sky, but if you were able to measure from one side of it to the other – known as its diameter – then you would get a distance of 3,475km (2,160mi). That's how far San Francisco and Cleveland are from each other!

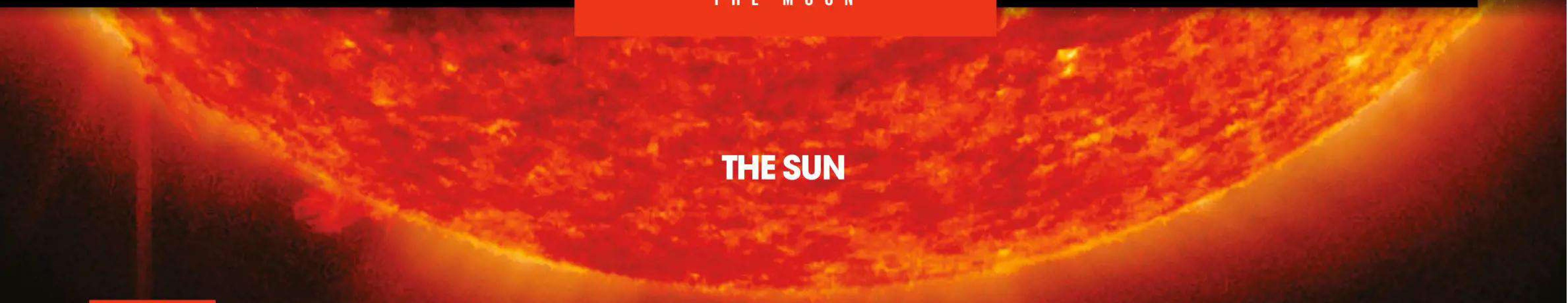


How far is the Moon?

Astronomically speaking, the Moon isn't that far away. An analogy would be if you used a basketball to represent the Earth and a tennis ball to represent the Moon, they would only be 7.3m (24ft) apart.

Gravity explained

Since it's lighter than Earth, our Moon's gravity is lower – that means you can jump higher on the lunar surface.



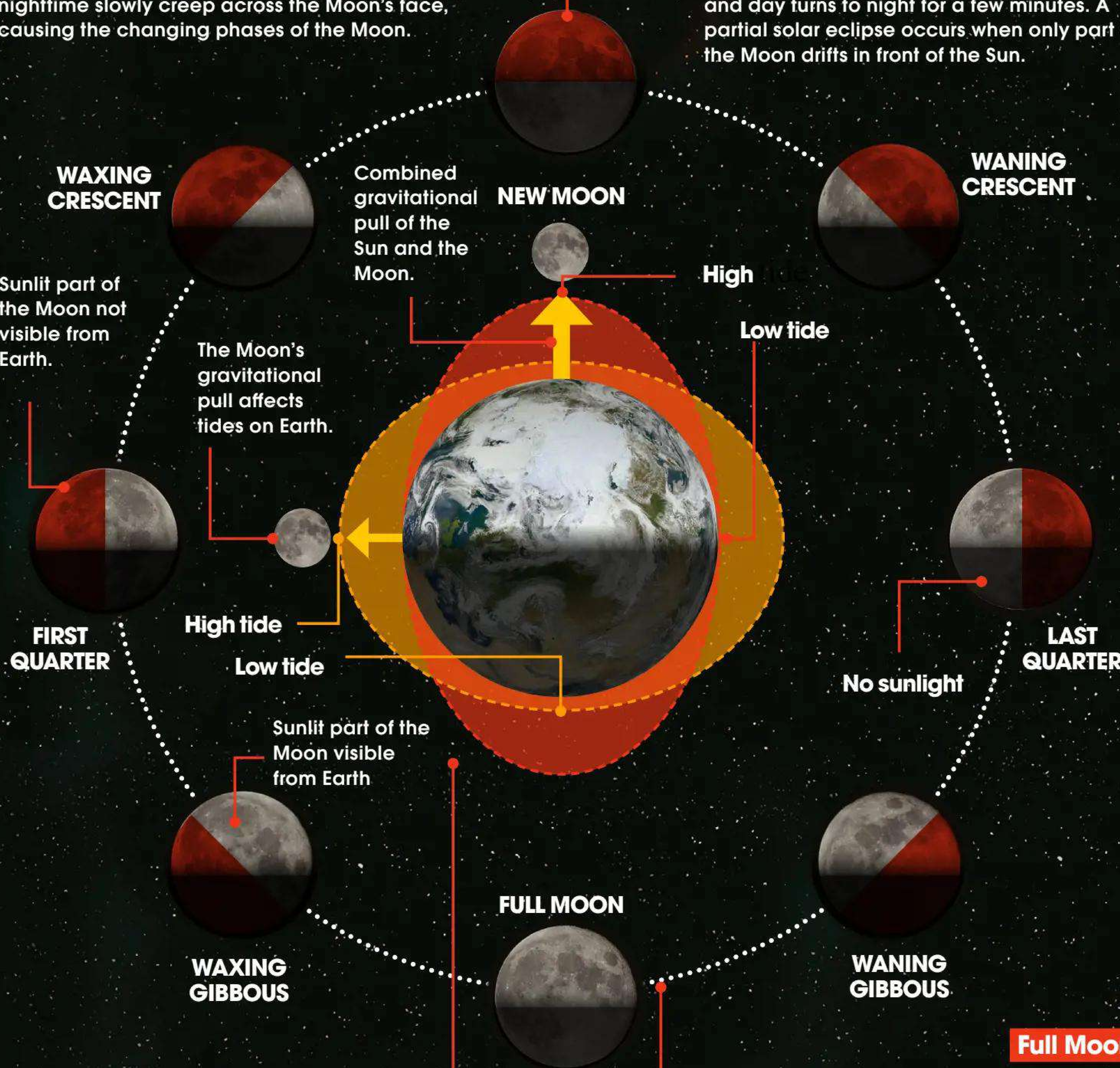
New Moon
When the near side is completely in night time, with the far side in day time, we call it a New Moon.

Phases of the Moon

Our companion in space, the Moon plays an important part in some interesting phenomena

Phases
As the Moon pirouettes on its axis and dances around the Earth on its orbit, a lunar day lasts almost as long as an Earth month. Because the Moon always shows the same face to us, we see nighttime slowly creep across the Moon's face, causing the changing phases of the Moon.

Eclipse
When the Moon moves into Earth's shadow, the Moon becomes eclipsed and turns dark, sometimes blood red. When Earth moves into the shadow of the Moon, the Sun is eclipsed and day turns to night for a few minutes. A partial solar eclipse occurs when only part of the Moon drifts in front of the Sun.



Full Moon
When the near side is fully in daylight, we say the Moon is full.

Tides
Ever wondered why the tide is in while at other times it's out? It's all to do with the gravity of the Moon as it moves around the Earth, as well as the Sun. Our lunar companion's gravity pulls the large bodies of water toward it, generating two tides per day.

Orbit
Our natural satellite takes around 27.3 days to complete one lap around our planet, orbiting at a speed of around 1km/s (0.62mi/s). The Moon is at an average distance of around 385,000km (238,900mi) from the Earth's centre.

Once upon a time, the lunar seas were thought to be seas of water by early astronomers. In reality the Moon is bone dry – the lunar rock samples brought back by the Apollo missions have been analysed over and over again and have been found to contain barely any water molecules at all, containing just a few parts per million.

However, while there may not be much water inside the Moon – a result of the way the Moon formed from the debris of a giant impact on Earth – in deeply shadowed regions at the poles of the Moon, on crater floors where no sunlight ever reaches, large quantities of water-ice lurk. This ice has been brought to the Moon by comets and asteroids that have crashed into it, and we discovered this by crashing our own impactor into the lunar surface.

A NASA spacecraft, called LCROSS, the Lunar Crater Observation and Sensing Satellite, found water-ice inside a crater at the lunar south pole called Cabeus. The upper stage of the rocket that launched LCROSS crashed into the crater ahead of LCROSS, allowing the NASA probe to measure the amount of water in the debris plume from the impact. Then India's Chandrayaan-1 satellite, orbiting the Moon, discovered an estimated 600 million tons of water-ice in permanently shadowed craters at the lunar north pole. The poles would be ideal places to locate future human bases: the water could be used for drinking, but also broken apart into oxygen atoms for breathing and hydrogen for rocket fuel.

The last astronaut to walk on the Moon did so in 1972, but there are plans to return in the near future with NASA's Artemis program. Using the Space Launch System – featuring the most powerful rocket since the Saturn V took the Apollo mission to the Moon – and the Orion spacecraft, these upcoming missions hope to send astronauts back to our lunar neighbour within the next decade. These missions will also include the first female lunar astronauts, and a long-term goal is to establish a permanent base there. So, whenever we go back, it may be for good, and when we do, it will fully transform the Moon into a new home away from home.

Far side

This is the side of the Moon we can't see without taking a mission to the Moon. You might be surprised to learn that it looks different to the near side.

18 per cent visibility

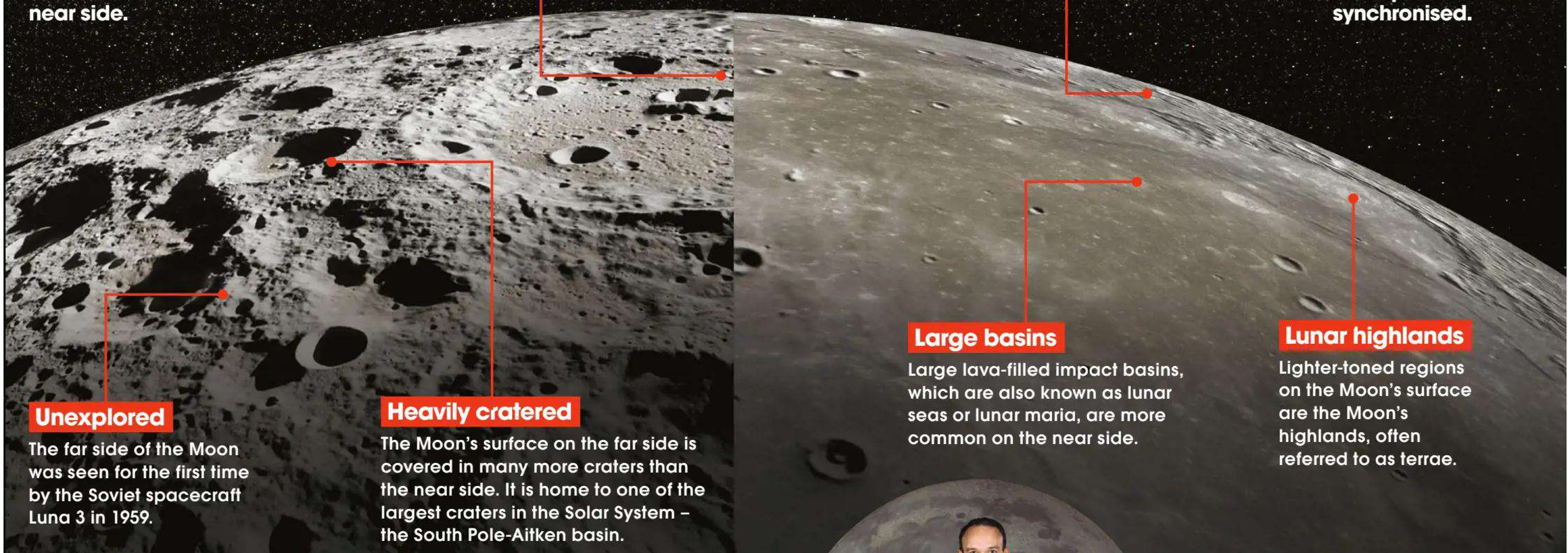
Since the Earth undergoes libration – in other words it oscillates in its orbit – then we catch a glimpse of 18 per cent of its far side.

Thinner crust

The near side of the Moon has a thinner crust than the far side. The Moon's chaotic formation is thought to be responsible for this.

Near side

The near side of the Moon is the face – or hemisphere – that we always see. This is because the Moon and Earth's spins are synchronised.



Large basins

Large lava-filled impact basins, which are also known as lunar seas or lunar maria, are more common on the near side.

Lunar highlands

Lighter-toned regions on the Moon's surface are the Moon's highlands, often referred to as terrae.

Unexplored

The far side of the Moon was seen for the first time by the Soviet spacecraft Luna 3 in 1959.

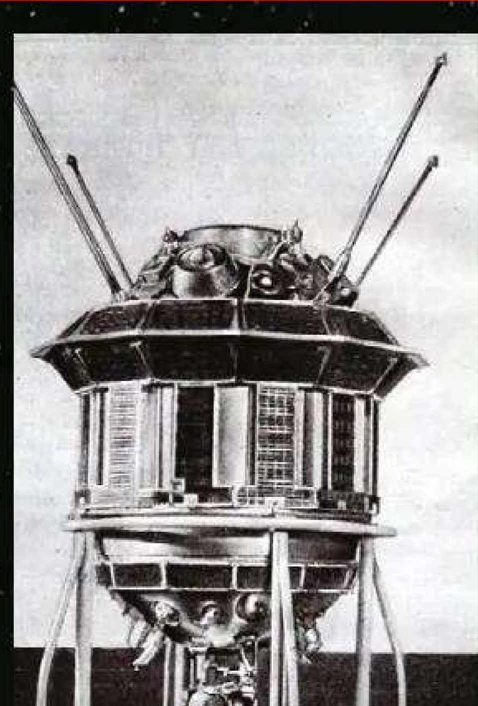
Heavily cratered

The Moon's surface on the far side is covered in many more craters than the near side. It is home to one of the largest craters in the Solar System – the South Pole-Aitken basin.

Moon exploration history

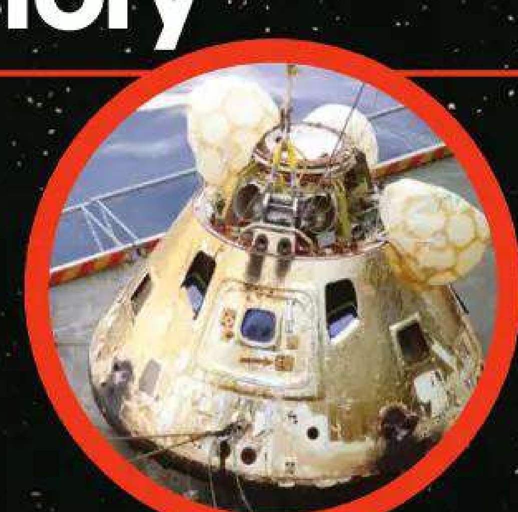
1959

The third space probe to be sent to the Moon, the Soviet spacecraft Luna 3, was an early attempt at imaging the far side of the Moon.



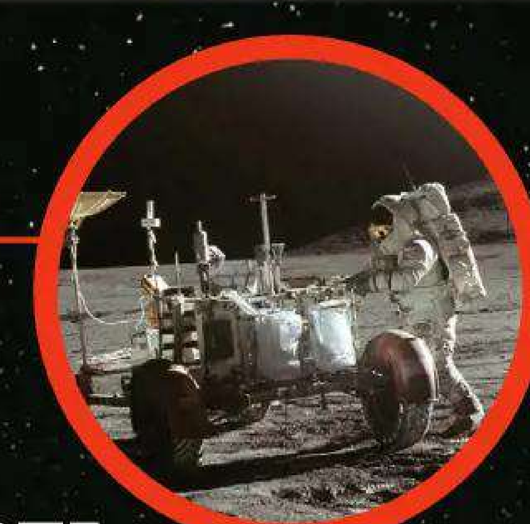
1968

The second human spaceflight mission to the Moon, Apollo 8, became the first manned spacecraft to enter lunar orbit before safely returning to Earth.



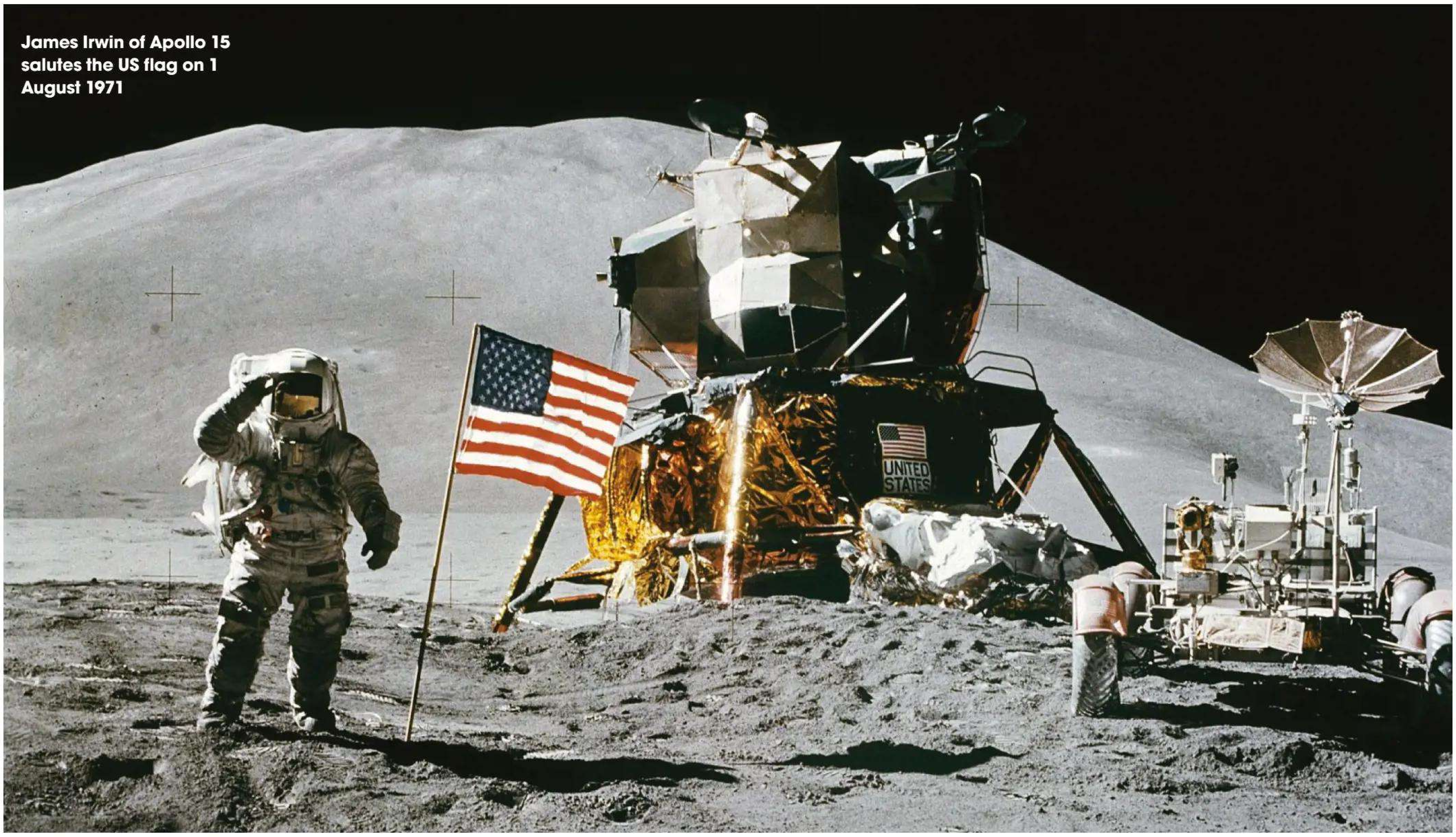
1969

Carrying Americans Neil Armstrong and Buzz Aldrin, Apollo 11 represented "one small step for a man, one giant leap for mankind" when they became the first to step onto the lunar surface. Astronaut Michael Collins piloted the command spacecraft in lunar orbit.



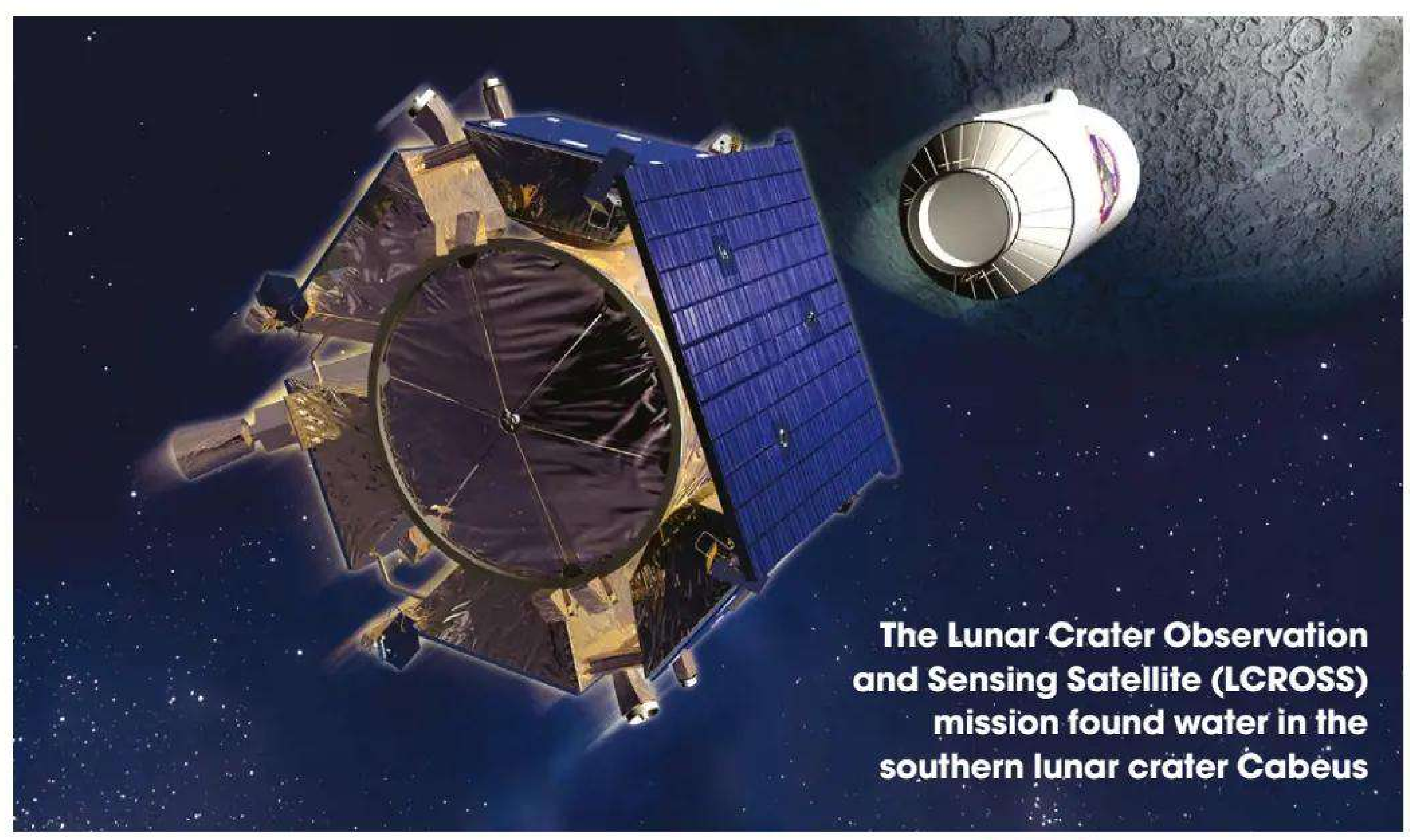
1971

Dubbed as the most successful manned mission of its time, Apollo 15 was the first mission on which the Lunar Roving Vehicle was used. Its astronauts spent three days on the Moon.

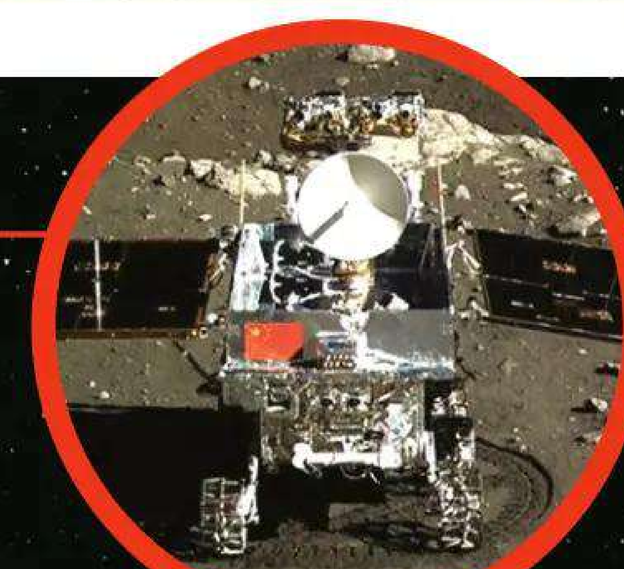


James Irwin of Apollo 15 salutes the US flag on 1 August 1971

Apollo 17 was the final mission of the USA's lunar landing program



The Lunar Crater Observation and Sensing Satellite (LCROSS) mission found water in the southern lunar crater Cabeus



1972
Apollo 17 marked the end of the America's lunar landing program. Being a 'J-type mission', Apollo 17 included a three-day lunar surface stay and a Lunar Roving Vehicle.

2008
India's first lunar probe, Chandrayaan-1, was comprised of a lunar orbiter and impactor. The impactor probe struck the south pole of the Moon.

2009
The Lunar Reconnaissance Orbiter (LRO), which is currently in orbit around the Moon, maps the lunar surface to identify safe landing sites.

2011
Made to crash into the Moon's surface when its mission came to an end in 2012, the Gravity Recovery and Interior Laboratory (GRAIL) was made of two probes that mapped the Moon's gravitational field.

2013–present
In 2013, China's Yutu rover "Jade Rabbit" made the first soft landing on the Moon since 1976. Its successor, Yutu-2, landed in 2019 and as of 2024 is the longest-lived lunar rover.

Supernovas

With more energy than a billion Suns, a size greater than our solar system and the potential to destroy entire planets millions of miles away, some stars certainly know how to go out with a bang

When we delve into certain realms of astronomy, the scale of events and objects are often impossibly large to imagine. If we think of planets like Earth and Mars we can at least get some sort of grasp as to their size, as we can consider them relative to other bodies. As we get to bigger objects, like Jupiter and the Sun, our understanding gets somewhat muddled, but we can still comprehend how enormous they are by using Earth as a starting point (for example, the Sun is over 100 times the size of Earth).

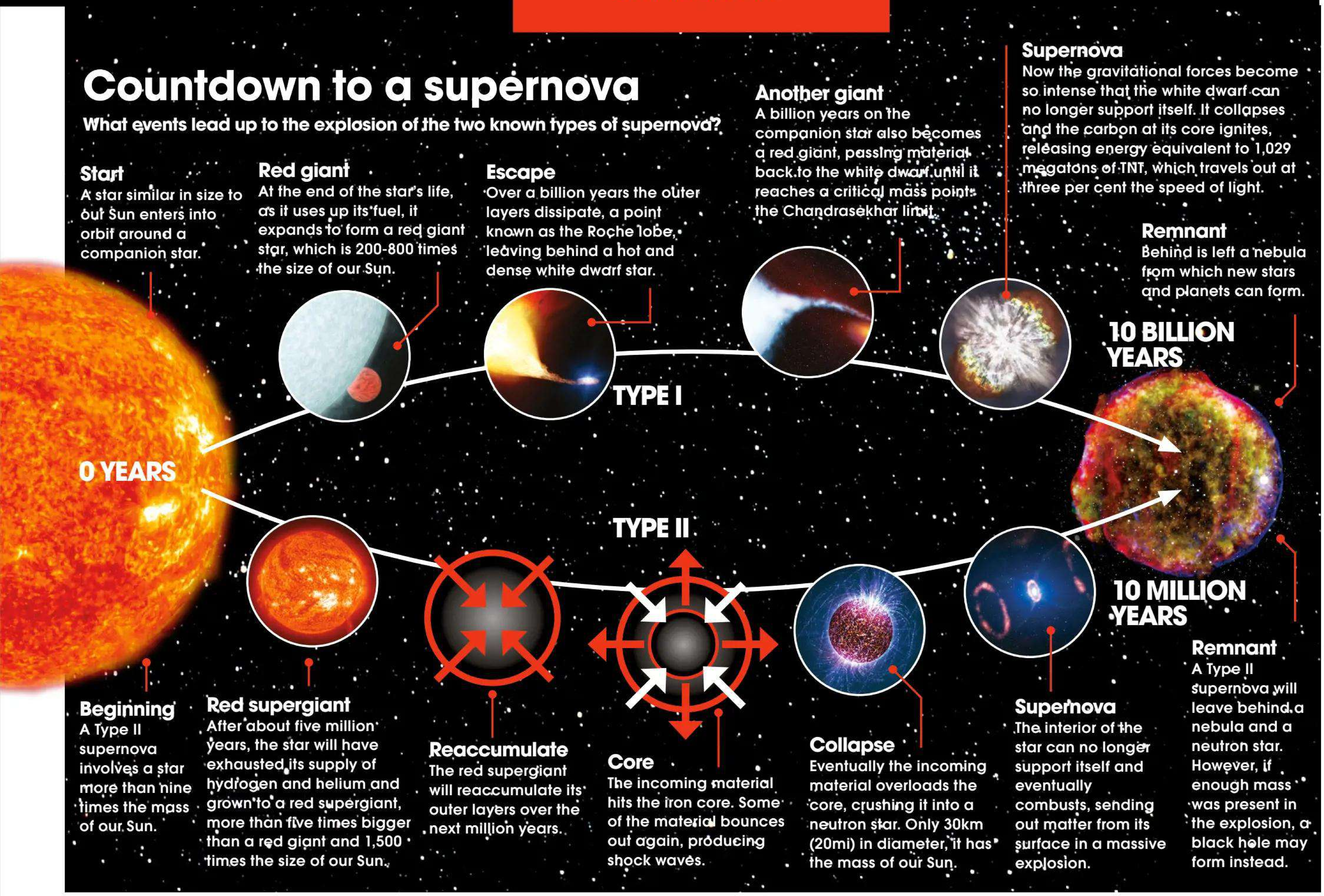
It's when we get to the larger celestial occurrences, like supergiant stars and black holes, however, that things really start to get unfathomable. When it comes to mammoth celestial events like supernovas, it's hard to get our heads around just how large and powerful they are.

Supernovas have fascinated astronomers for millennia, appearing out of nowhere in the night sky and outshining other stars with consummate ease. The first recorded supernova, known today as SN 185, was spotted by Chinese astronomers in 185 CE and it was apparently visible for almost an entire year.

While this is the first recorded sighting, there have doubtless been many supernovas in preceding years that confounded Earth dwellers who were unable to explain the sudden appearance of a bright new star in the sky.

Countdown to a supernova

What events lead up to the explosion of the two known types of supernova?



Images © ESO/L Calçada/JPL-Caltech/ESA/HST

"Geminga is the closest known supernova to have exploded near Earth, as little as 290 light years away"

One of the most notable supernova events likely occurred about 340,000 years ago when a star known as Geminga went supernova. Although it was unrecorded, astronomers have been able to discern the manner of its demise from the remnant neutron star it left behind.

Geminga is the closest known supernova to have exploded near Earth, as little as 290 light years away. Its proximity to Earth meant that it might have lit up the night sky for many months, casting its own shadows and rivalling the moon for brightness, turning night into day. So bright and large was this supernova that the ancients would have seen the light of it stretching from horizon to horizon.

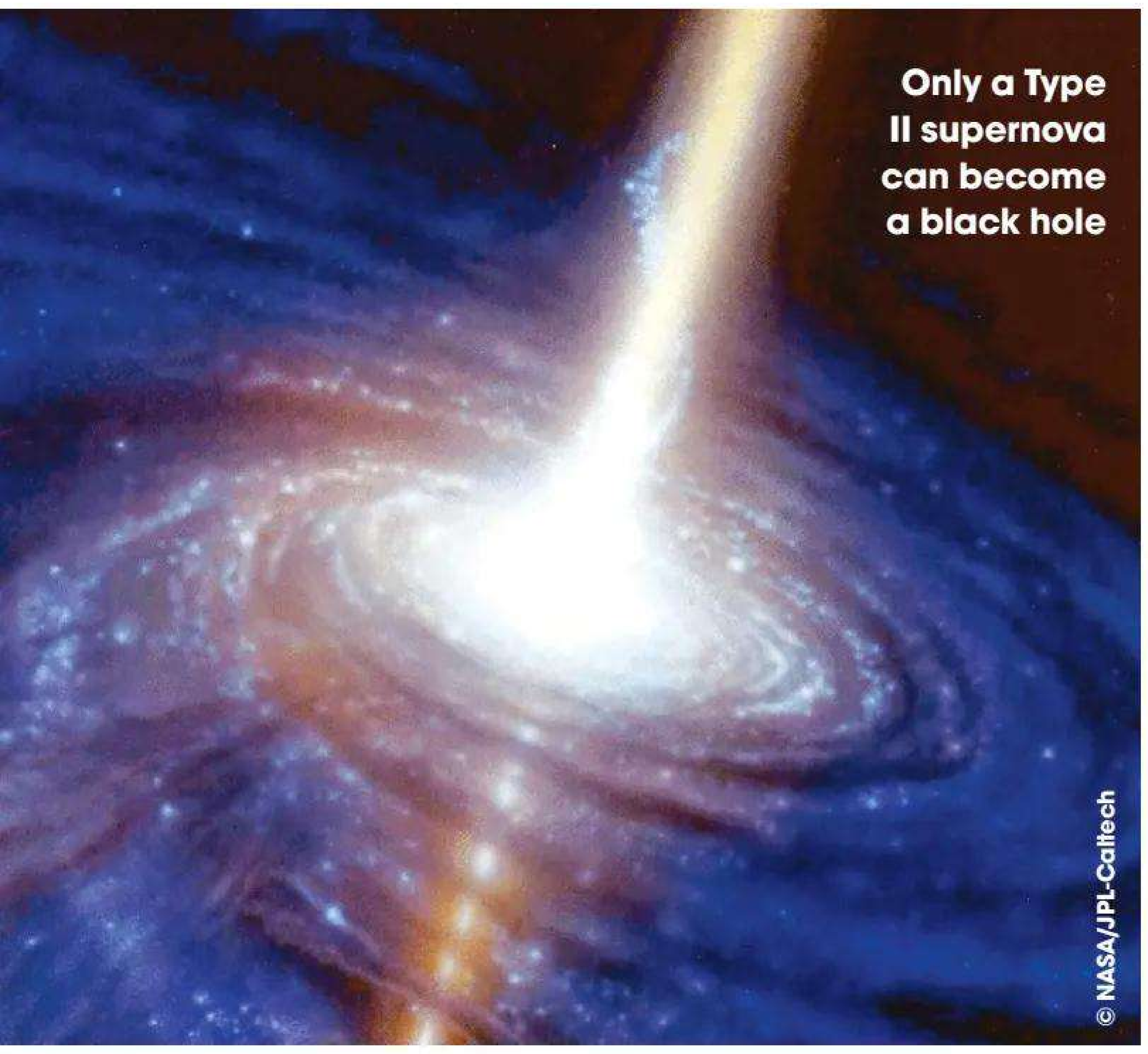
Left behind after this supernova was a neutron star rapidly rotating at about four times a second, the nearest neutron star to Earth and the third-largest source of gamma rays to us in our observations of the cosmos. Other notable stellar explosions include Supernova 1987A, a star located in the Large Magellanic Cloud that went supernova in 1987. This originated from a supergiant star known as Sanduleak -69°202. It almost outshone the North Star (Polaris) as a result of its brightness, which was comparable to 250 million times that of the Sun.

It is a testament to the scale of these explosions that even ancient civilisations with limited to no astronomical equipment were able to observe them. Supernovas are bright not only visually but in all forms of electromagnetic radiation. They throw out X-rays, cosmic rays, radio waves and, on occasion, may be responsible for causing giant gamma-ray bursts, the largest known explosions in the universe. It is by measuring these forms of electromagnetic radiation that astronomers are able to glean


Some supernovas leave behind spinning neutron stars known as pulsars

such a clear picture of the formation and demise of supernovas. In fact, it is estimated that 99 per cent of the energy that a supernova exerts is in various forms of electromagnetic radiation other than visible light, making the study of this invisible (to the naked eye at least) radiation incredibly important, and something to which many observatories worldwide are tuned.

Another type of stellar explosion you may have heard of is a nova. This is similar in its formation to a supernova, but there is one key difference post-explosion: a supernova obliterates the original star, whereas a nova



Only a Type II supernova can become a black hole

© NASA/JPL-Caltech

leaves behind an intact star somewhat similar to the original progenitor of the explosion.

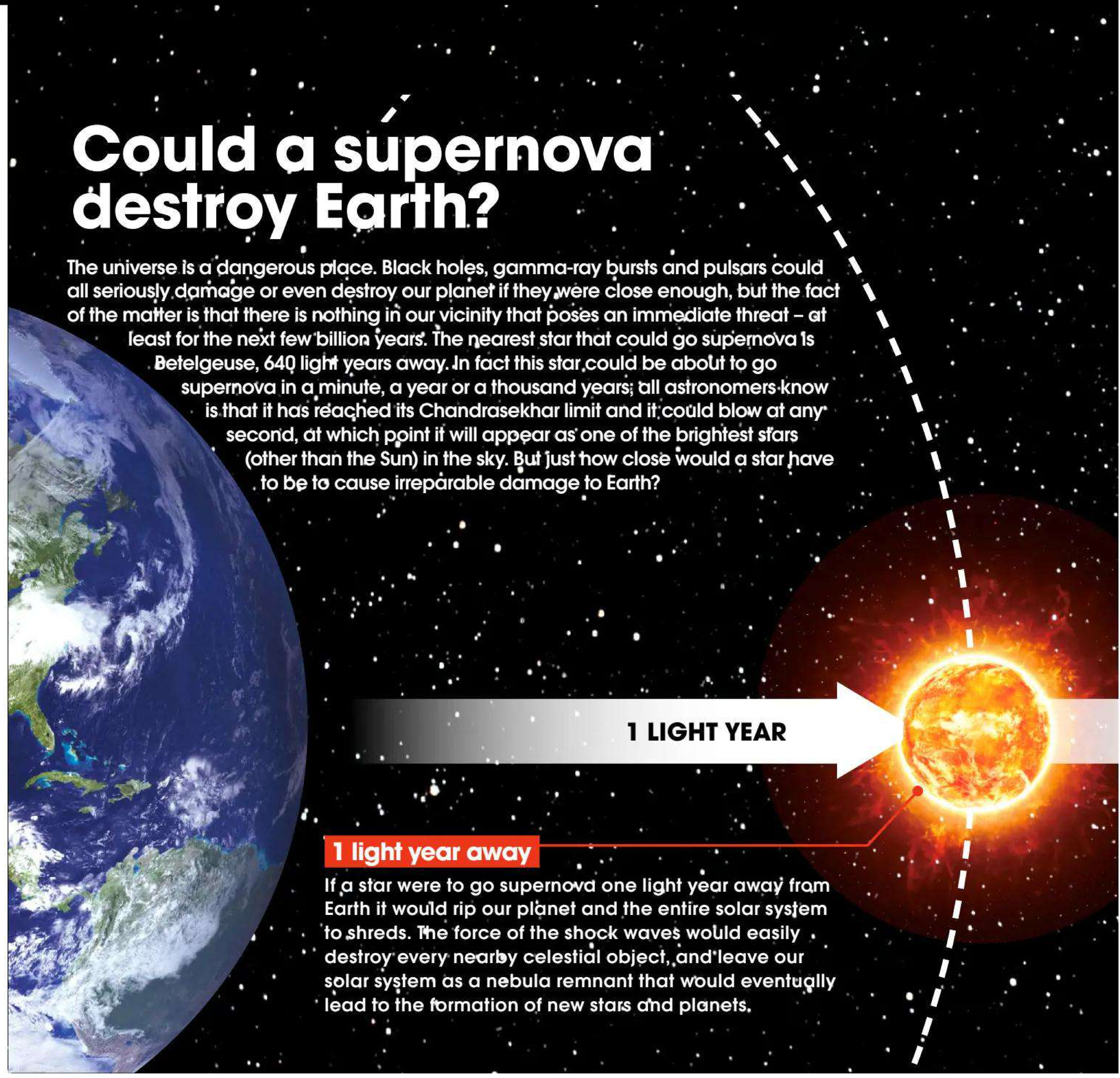
Our understanding of the universe so far suggests that pretty much everything runs in cycles. For example, a star is born from a cloud of dust and gas, it undergoes nuclear fusion for billions of years, and then destroys itself in a fantastic explosion, creating the very same dust and gas that will lead to the formation of another star. It is thanks to this cyclic nature of the universe that we are able to observe events that would otherwise be extremely rare or nonexistent. If stars were not constantly reforming, there would be none left from the birth of the universe 13.7 billion years ago.

As destructive as they may be, supernovas are integral to the structure and formation of the universe. It is thought that the solar system itself formed from a giant nebula left behind from a supernova while, as mentioned earlier, supernovas are very important in the life cycle of stars and lead to the creation of new stars as the old ones die out. This is because a star contains many of the elements necessary for planetary and stellar formation including large amounts of helium, hydrogen, oxygen and iron, all key components in the structure of celestial bodies. On top of these, many other elements are thought to form during the actual explosion itself.

There's no doubt that supernovas are one of the most destructive forces of the universe, but they're also one of the most essential to the life cycle of solar systems. As we develop more powerful telescopes over the coming years, we will be able to observe and study them in more detail, and possibly discover some that do not fall into our current classifications. The study of supernovas alone can unlock countless secrets of the universe, and we'll be able to learn more about the cosmos as a whole.

Could a supernova destroy Earth?

The universe is a dangerous place. Black holes, gamma-ray bursts and pulsars could all seriously damage or even destroy our planet if they were close enough, but the fact of the matter is that there is nothing in our vicinity that poses an immediate threat – at least for the next few billion years. The nearest star that could go supernova is Betelgeuse, 640 light years away. In fact this star could be about to go supernova in a minute, a year or a thousand years; all astronomers know is that it has reached its Chandrasekhar limit and it could blow at any second, at which point it will appear as one of the brightest stars (other than the Sun) in the sky. But just how close would a star have to be to cause irreparable damage to Earth?



1 light year away

If a star were to go supernova one light year away from Earth it would rip our planet and the entire solar system to shreds. The force of the shock waves would easily destroy every nearby celestial object, and leave our solar system as a nebula remnant that would eventually lead to the formation of new stars and planets.

This image of the Crab Nebula shows the visible (red) and X-ray (blue) radiation left after a supernova

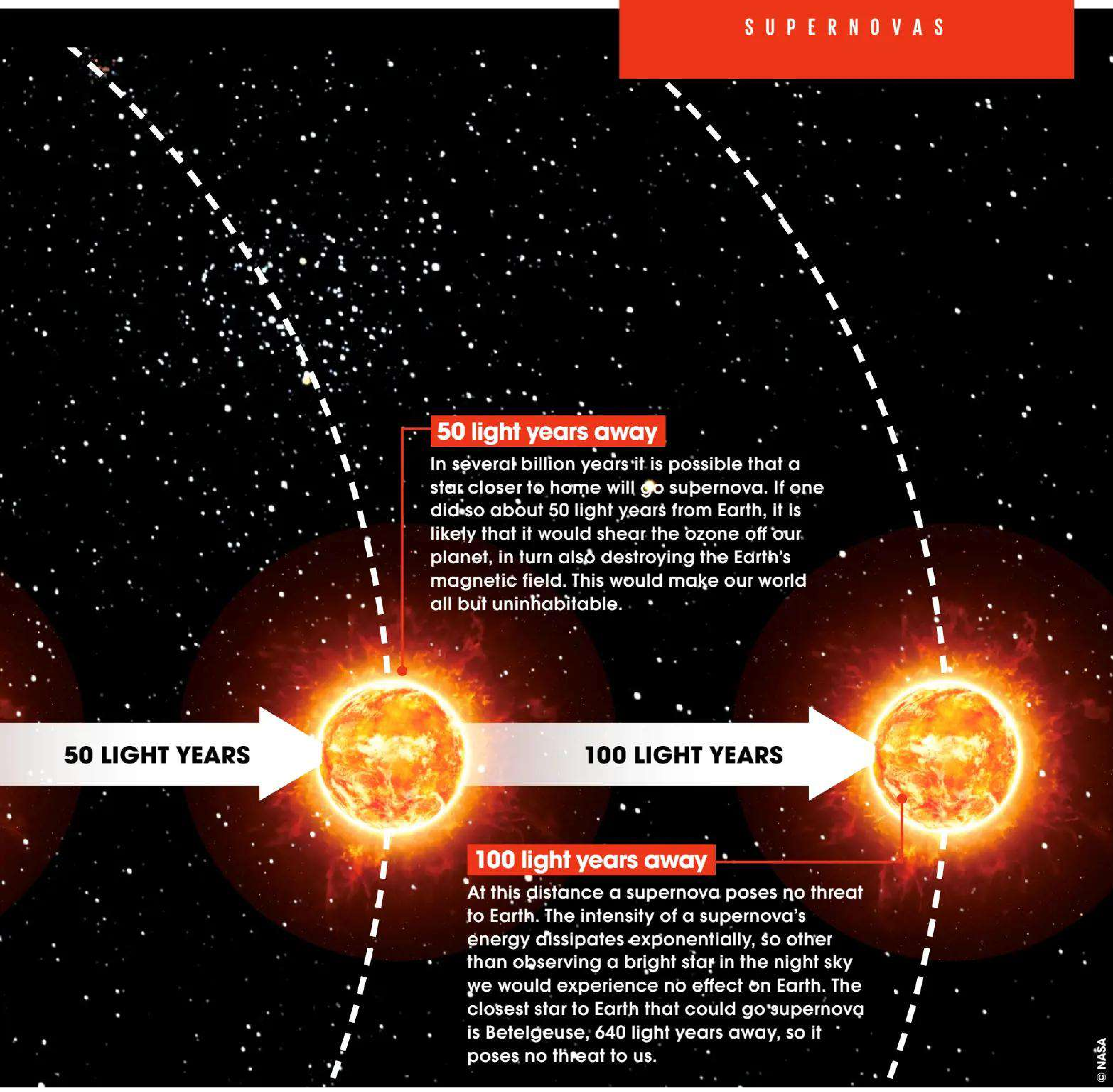
All that remains...

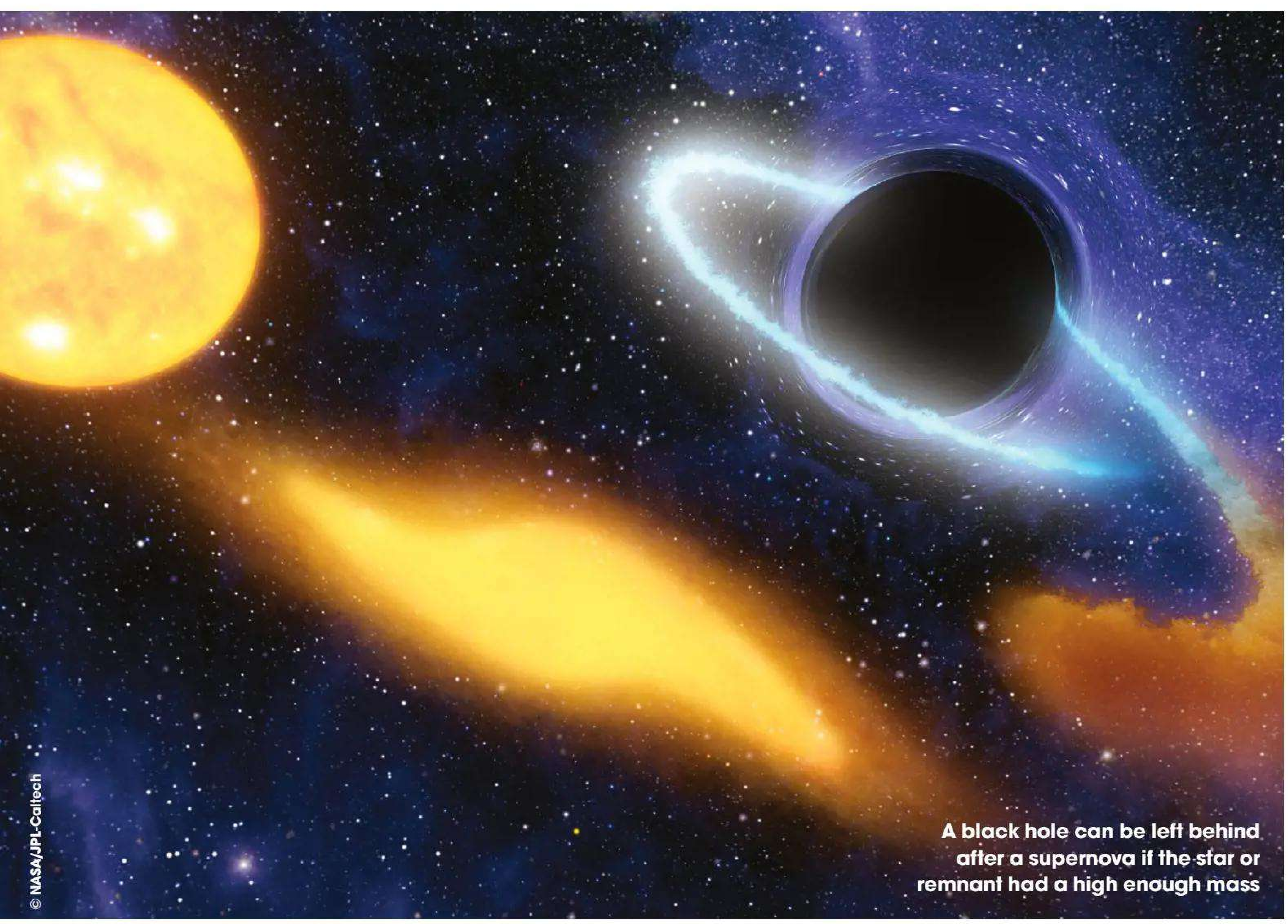
What is left behind once a star goes supernova?

Inside a massive star, before it goes supernova, the nuclei of light elements like hydrogen and helium combine to form the basic constituents of other celestial bodies and even life (such as carbon and oxygen). Stars release these vital elements when they go supernova, providing the material for new stellar and planetary formation.

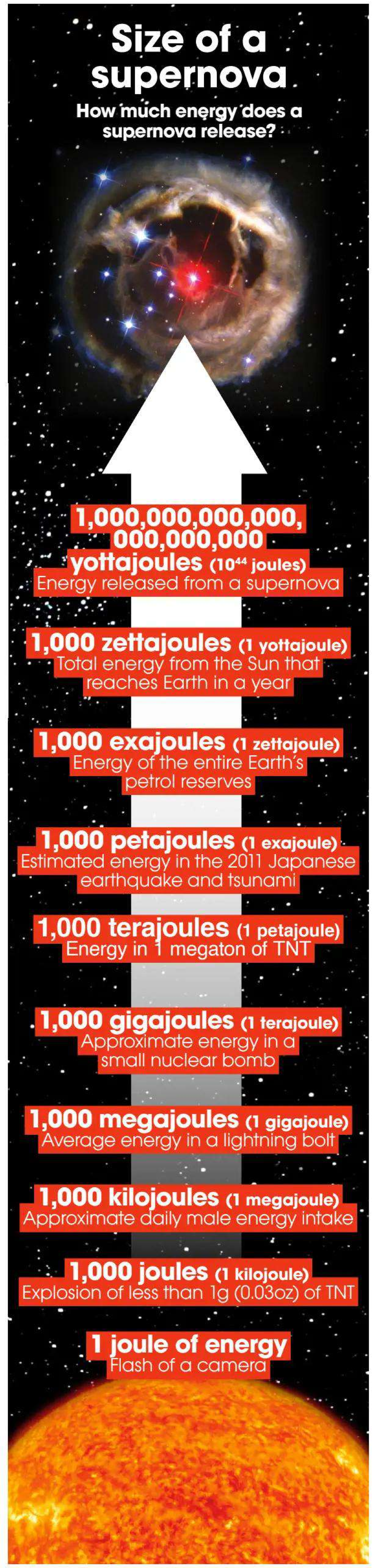
To date there are about 300 known supernova remnants in the universe. Depending on the type and mass of a supernova, the remnants left behind can be one of several things. In the vast majority of cases some form of nebula will be left behind. Inside this nebula will often be a spinning neutron star. The rate of spin of this neutron star, also known as a pulsar, depends on the original mass of the exploded star, with some pulsars rotating upwards of a thousand times per minute!

These highly dense stars contain the mass of the Sun packed into an area no bigger than the city of London. If the supernova remnant exceeds four solar masses (the mass of our Sun), due to an extremely heavy initial star or by more material accumulating around the remnant from nearby objects, then the remnant will collapse to form a black hole instead of continuing to expand.

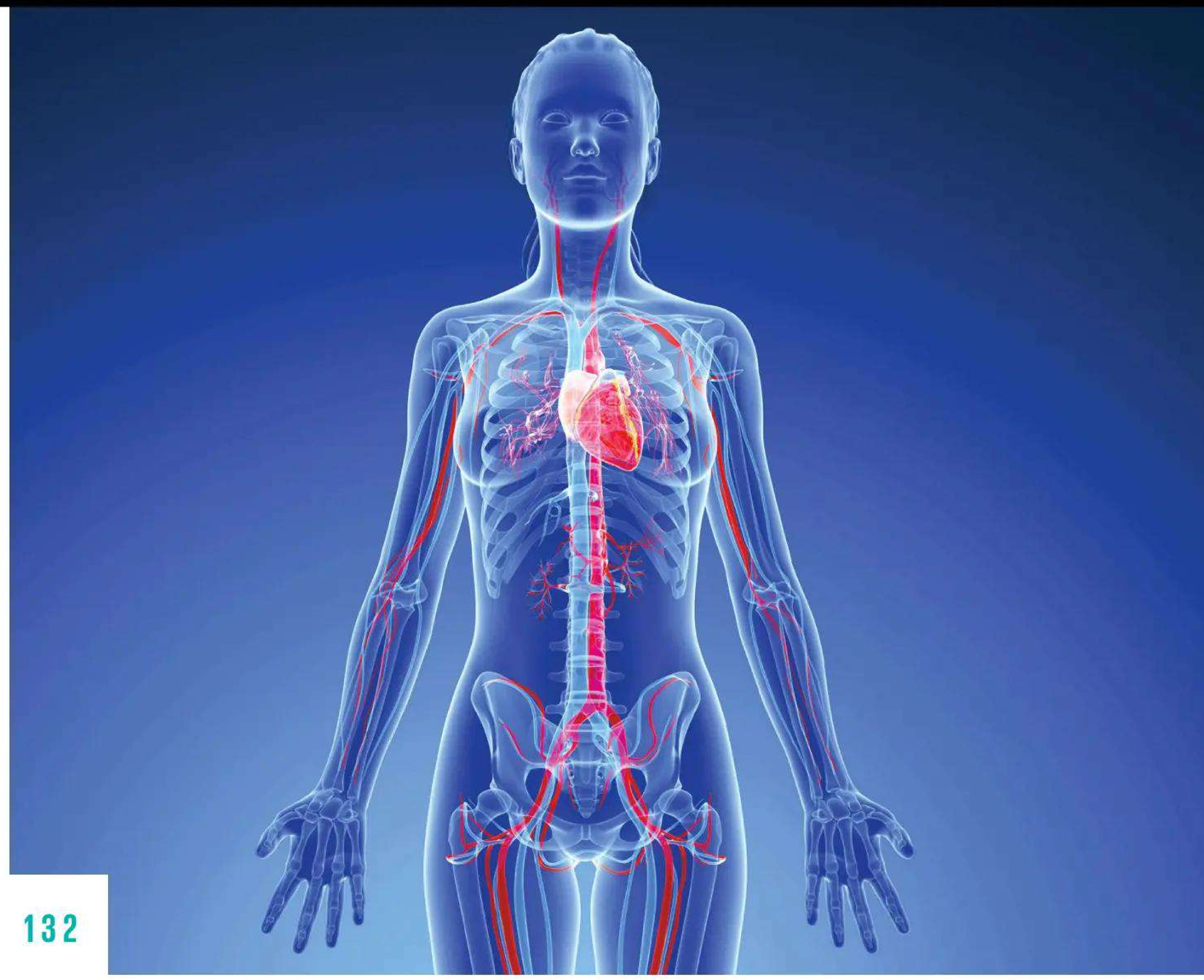




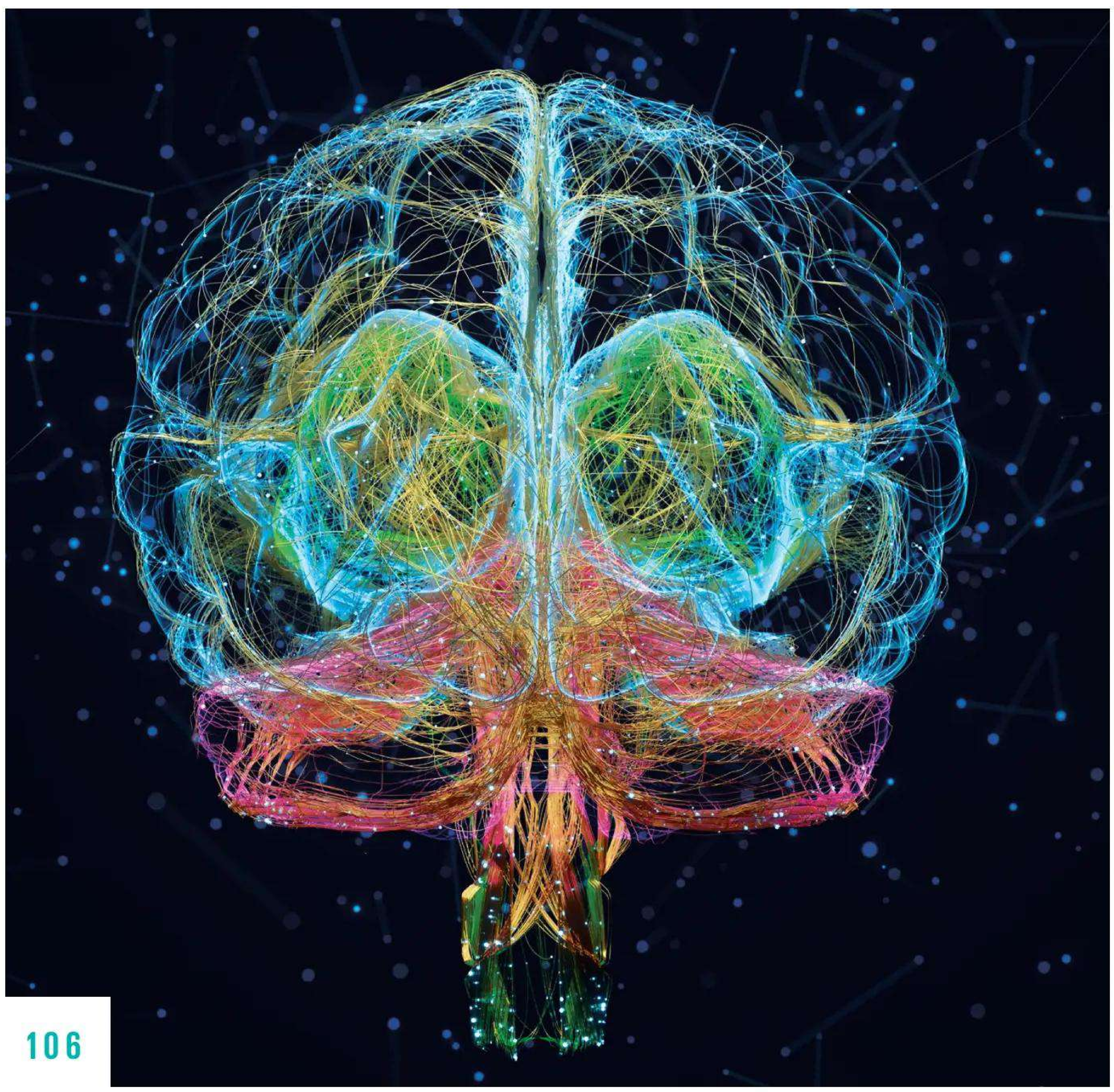
A black hole can be left behind after a supernova if the star or remnant had a high enough mass



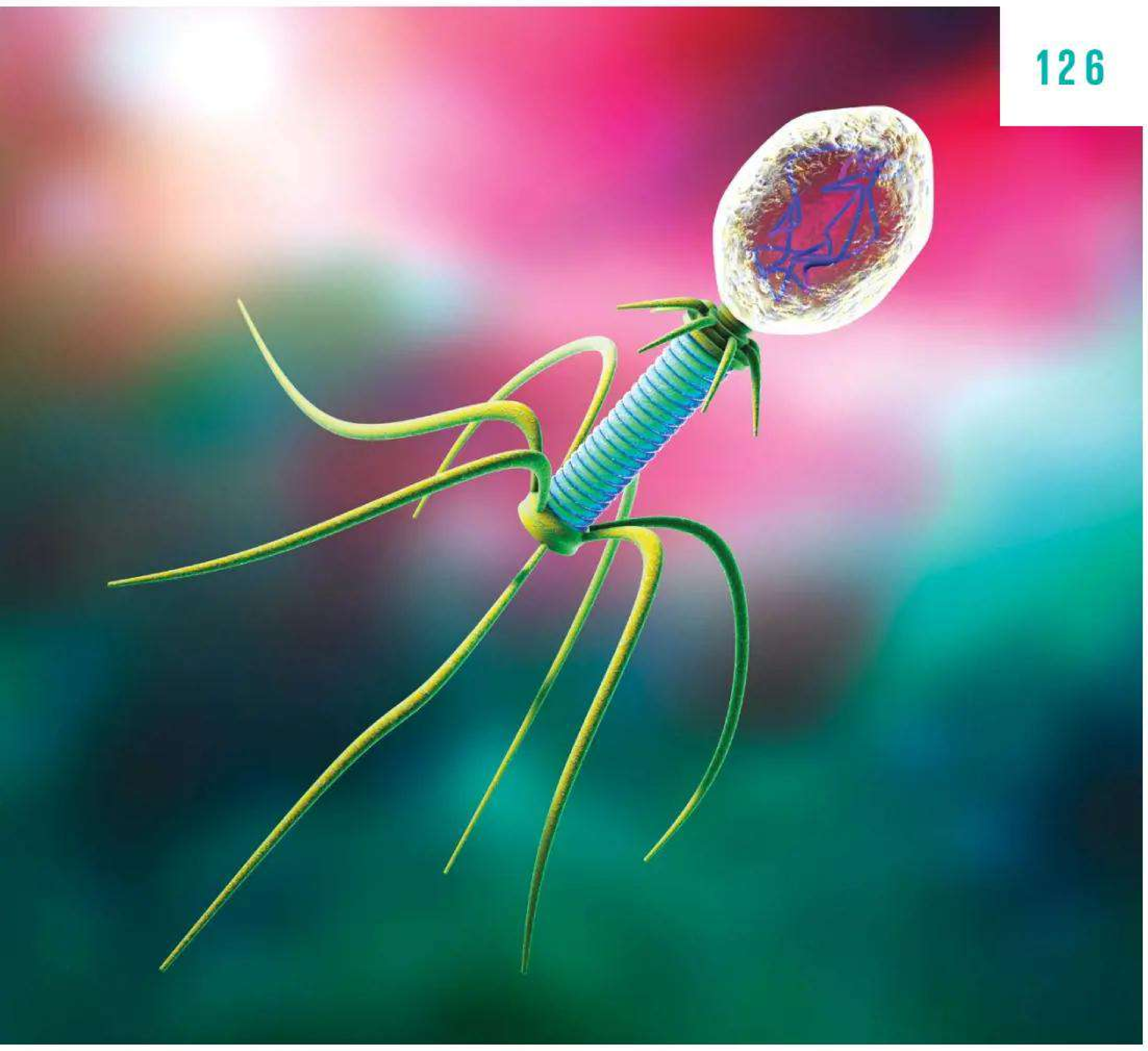
The Human Body



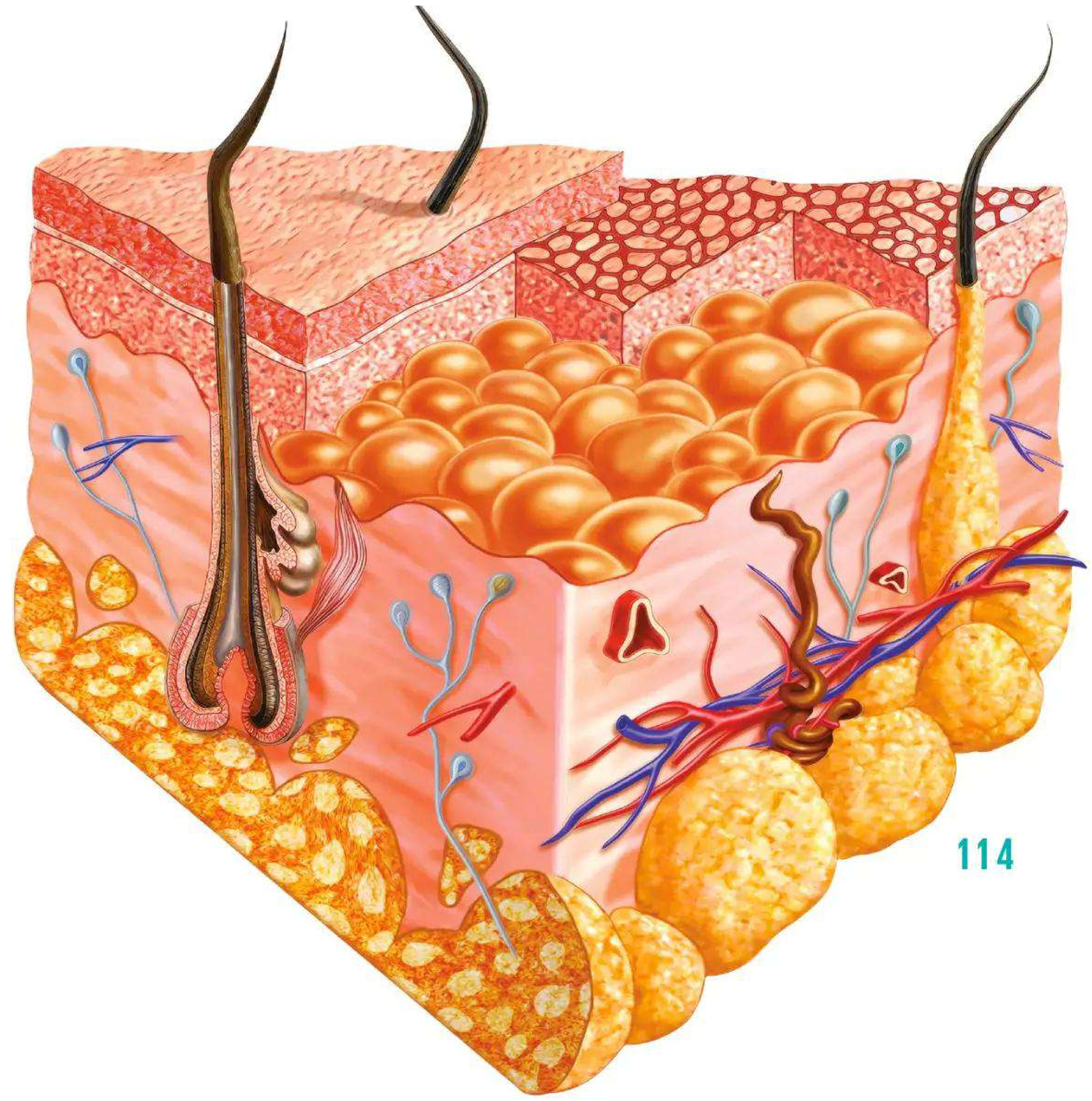
132



106

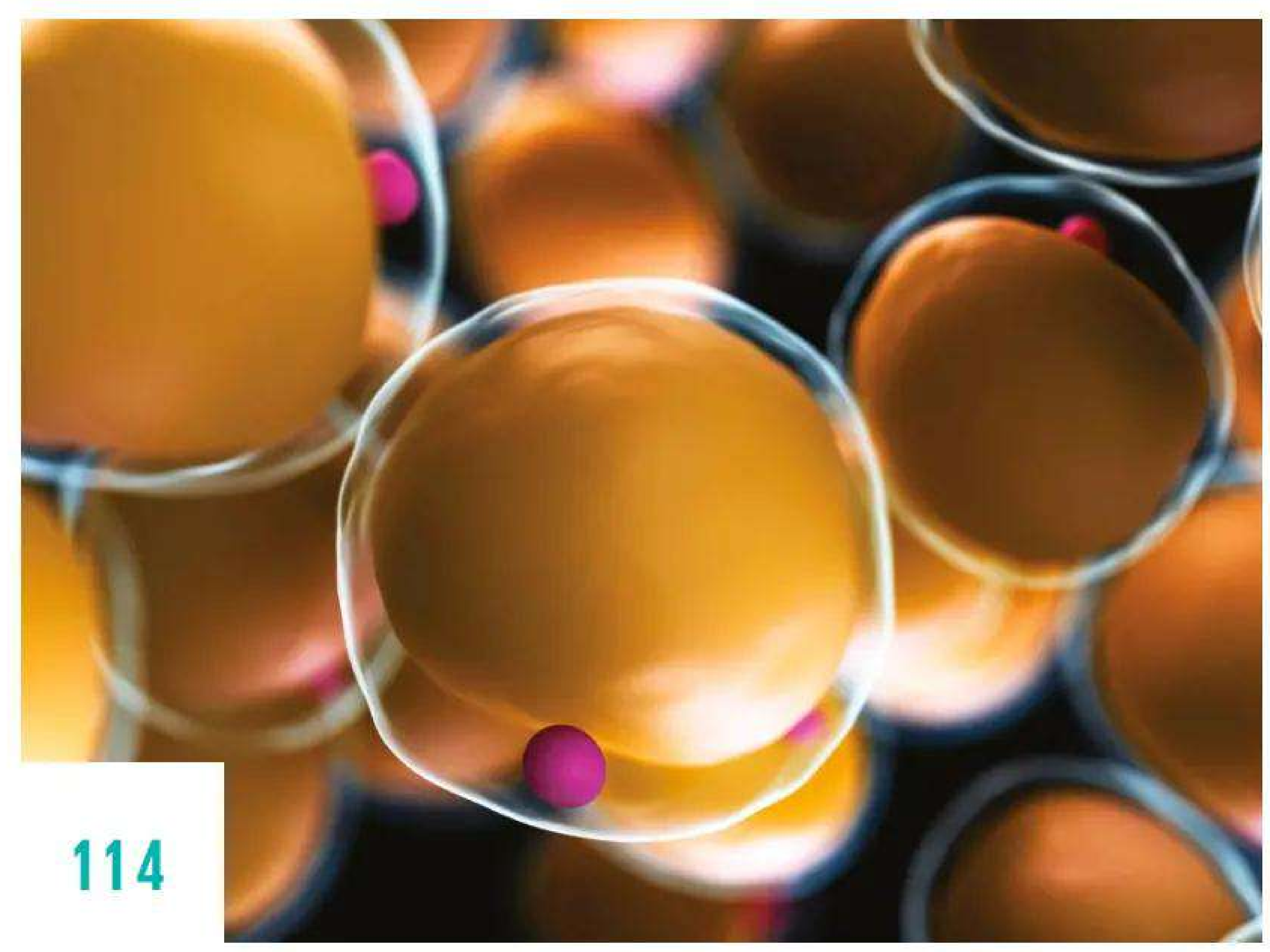


126

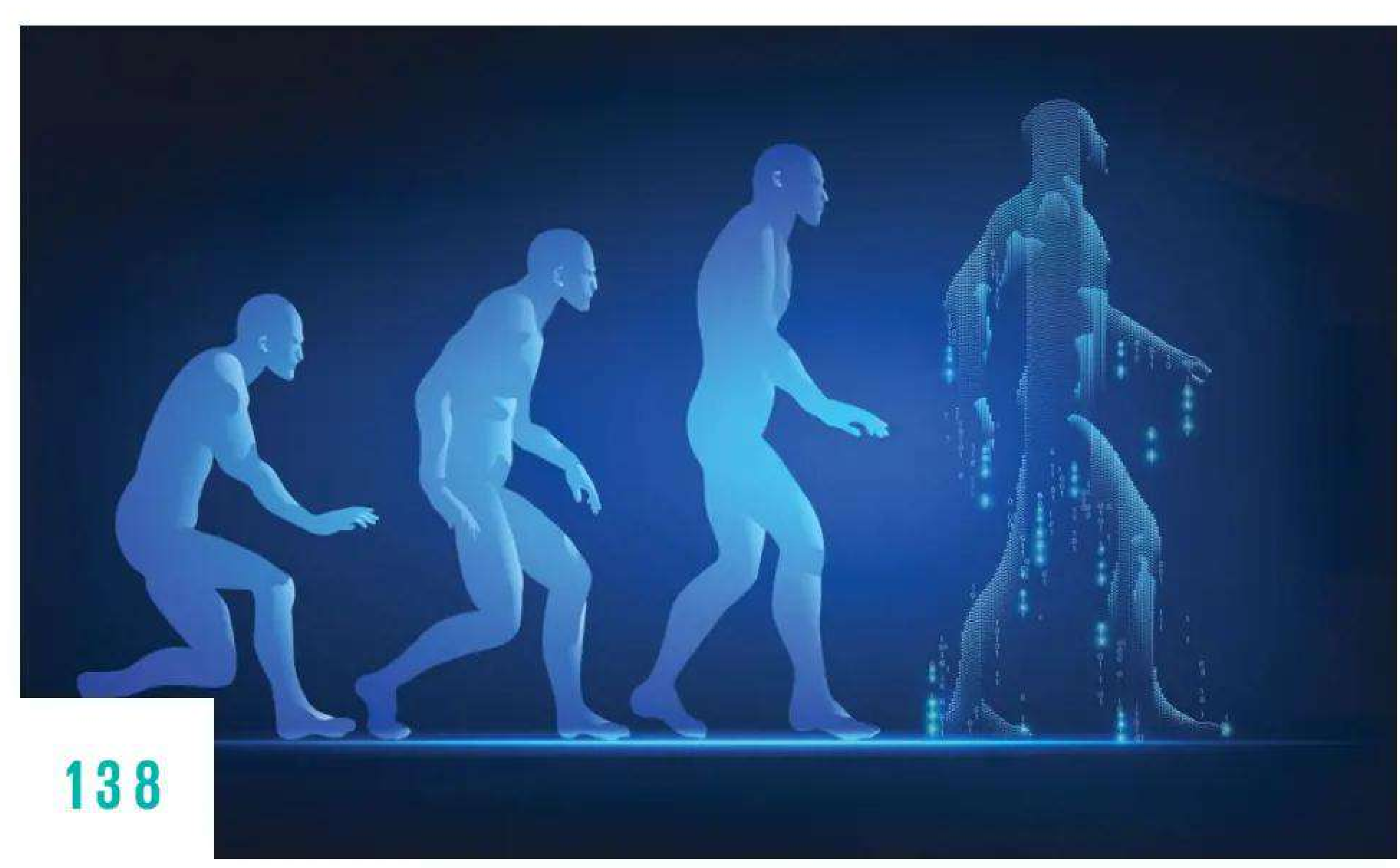


114

120



114



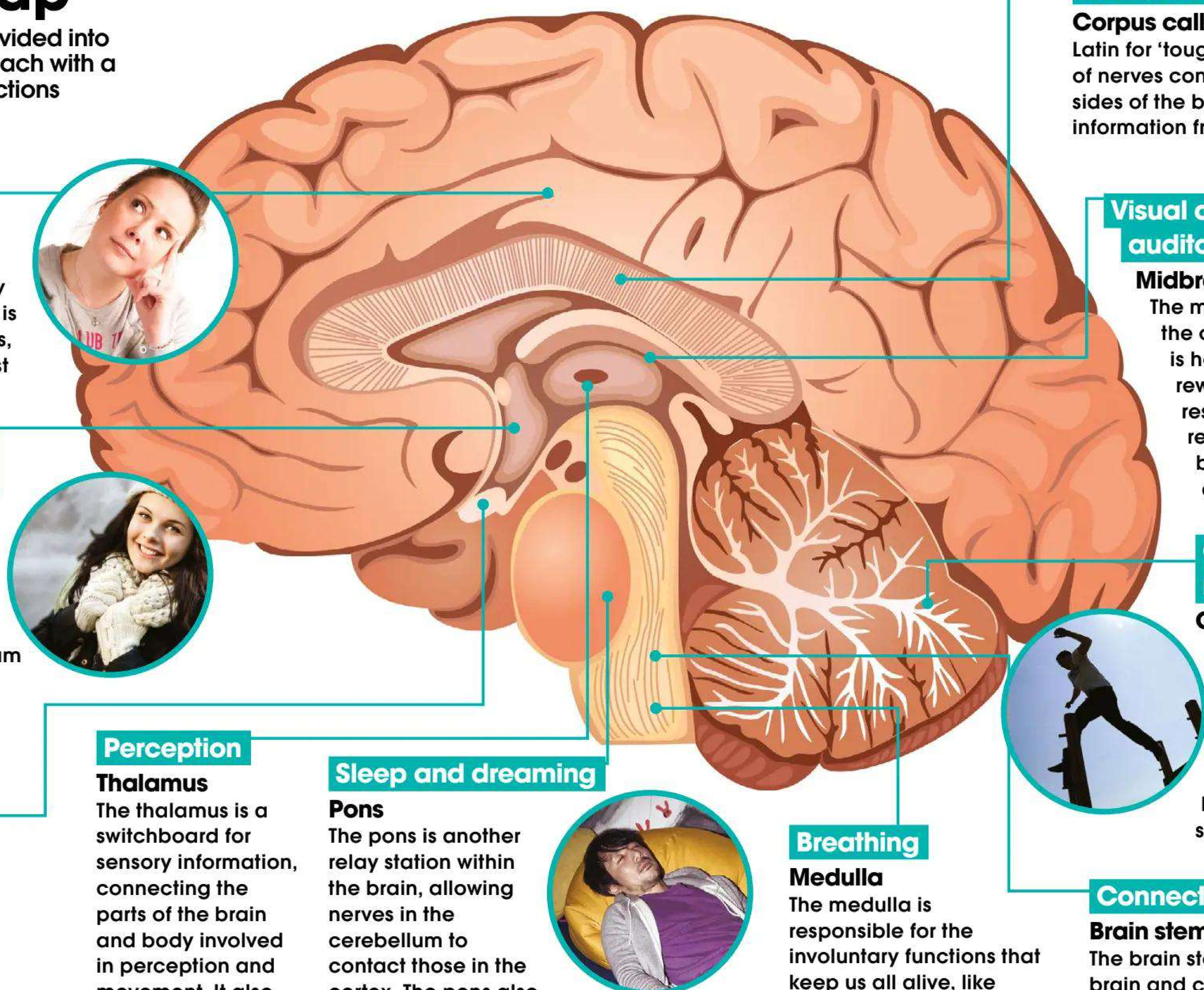
138

Your amazing brain

Modern neuroscience is unravelling the body's most complex organ and rebuilding it from the bottom up

Brain map

The brain can be divided into distinct structures, each with a specialist set of functions



Memory
Cerebrum
The cerebral cortex makes up the majority of the human brain. It is divided into four lobes, which handle the most complex of tasks, including planning, memory and vision.

Temperature and hydration
Hypothalamus
The hypothalamus is responsible for maintaining equilibrium within the body. It monitors and adjusts things like the body's temperature and hydration.

Hormones
Pituitary gland
This pea-sized gland is connected to the hypothalamus and produces hormones, passing on chemical messages instead of electrical impulses.

Perception
Thalamus
The thalamus is a switchboard for sensory information, connecting the parts of the brain and body involved in perception and movement. It also controls the sleep/wake cycle.

Sleep and dreaming
Pons
The pons is another relay station within the brain, allowing nerves in the cerebellum to contact those in the cortex. The pons also plays an important role in the sleep cycle and dreaming.

Breathing
Medulla
The medulla is responsible for the involuntary functions that keep us all alive, like breathing, swallowing and heartbeat.

Information transfer
Corpus callosum
Latin for 'tough body', this wide sheet of nerves connects the left and right sides of the brain, transferring information from one to the other.

Visual and auditory systems
Midbrain
The midbrain is buried near the centre of the brain and is home to part of the reward pathway, responsible for reinforcing positive behaviours and addiction.

Coordinated movement
Cerebellum
Cerebellum means 'little brain'. It is the control centre for coordinated movement, making fine adjustments before the signals are sent to the body.

Connects nerves
Brain stem
The brain stem marks the end of the brain and connects the nerves to the spinal cord. It contains two distinct structures, the pons and the medulla.

The human brain is the most complicated structure in the known universe. It has taken hundreds of millions of years of evolution to construct, and over the last seven million years, it has tripled in size. It weighs little more than a bag of sugar, but packed inside it are 86 billion neurons, linked together by over 100 trillion connections in a network more powerful than even the most advanced supercomputers ever built.

By far the largest part of the human brain is the forebrain, and like the brains of other mammals, it is covered in a thick layer of neurons known as the cerebral cortex. But in humans, this layer has been massively expanded – it has 1,000 times as many neurons as the same structure in a mouse, and it has not yet stopped evolving.

The smallest processing units in the cortex are known as neocortical columns, where each contains thousands of different connections. Over the course of evolution, these neocortical columns have been duplicated over and over again, until space in the skull started to run out. The cortex developed deep ridges and folds to fit more and more processing power into the same tiny space, and if unfolded, would cover an area measuring two square metres (21.5 square feet). The neurons that make up the brain crisscross over one another in a vast network and each individual cell makes up to 10,000 connections, building the most complex circuit in history.

In 2013, a team at the Centre for Regenerative Therapies in Dresden, Germany, examined the formation of neuron connections in cloned mice. They wanted to learn how much the structure of the brain is influenced by life experience. Because the mice were clones, each was genetically identical, meaning that any differences in their brains would be purely down to their environment. The mice lived in large cages, with lots of toys and places to explore, and after just a few months, differences became apparent in their brains. The most excitable, outgoing, curious mice had many more new nerves and new connections than their lazier counterparts; their brains had adapted as they learnt.

> **"While the underlying fabric of the brain is the same, every neuron in every brain is different"**

While the underlying fabric of the brain is the same, every neuron in every brain is different, and each makes its own unique path. Every brain is wired differently, and the unique set of connections is based on experiences.

Mapping the connections in the human brain is an enormous task and work is ongoing. The Human Connectome Project, launched in 2009, is designed to map the intricate connections between all of the neurons in the human brain,

in an effort analogous to the Human Genome Project. Computers can be programmed to trace the paths of neurons through brain-scan images, but even the most advanced machines make mistakes, and everything has to be double-checked by a human.

As an alternative, some research teams are trying a new approach: instead of using computers to analyse data, they use volunteers. In 2011, the online game Foldit made the headlines when players managed to solve a decade-old biological question. By tapping into the spatial skills of videogamers, researchers used volunteers to solve three-dimensional protein puzzles that a computer would struggle with. By playing the game, hundreds of people worked together to help solve the structure of a protein made by a simian retrovirus that causes AIDS-like symptoms in monkeys.

This approach is now being extended to the field of neuroscience and crowd-sourcing is being used to map the connections between neurons in the back of the eye. Tracking the intricate pathways of neurons in the brain is a difficult task for computers, but people are much better at spotting patterns.

EyeWire is a project designed to map the nerve connections in the human retina. Players are given a half-finished neuron and asked to work through slices of the brain, colouring in the connections. Each cube section is manually checked multiple times by different people, so if someone makes a mistake it is averaged out by the community. More experienced players oversee the work and can make changes if they feel they are needed. This approach speeds up the process by thousands of times.

Although projects like EyeWire provide a detailed and biologically accurate picture of what

The science of sleep

By monitoring the brain's electrical activity, scientists are unravelling the mystery of sleep

Thalamus

During wakeful periods, the thalamus transmits information to the cortex, but during sleep it becomes rhythmic, generating spindle oscillations, selectively preventing signals from passing.

Hypothalamus

The hypothalamus makes connections with areas of the brain involved in arousal and wakefulness. During sleep, it shuts down their activity.

Pineal gland

This small gland is linked to the retina via the hypothalamus. When it gets dark, the gland releases the hormone melatonin, helping to synchronise the body with the environment.

Suprachiasmatic nucleus

The SCN is the biological clock. It contains just 50,000 neurons and is connected directly to the eyes. When it is light, it releases a powerful 'alert' signal.

Cerebral cortex

This is involved in the highest functions of the human brain. Much of it is deactivated during sleep, but during dreaming, parts of the cortex are even more active than when we are awake.

Stage 1

The first stage of sleep is the transition period. It is very light and lasts just a few minutes. As the brain shuts down, there can be some twitching as the muscles relax.

Stage 2

As people enter the second stage of sleep, their breathing and heart rate slow down and their body temperature drops. Around half of sleep time is spent in stage-2 sleep.

Stage 3

The third stage of sleep is described as 'deep sleep' and is characterised by the presence of a slow delta-wave pattern, representing the underlying activity of the brain stem.

Stage 4

We spend about ten per cent of the night in this deep sleep stage. Breathing is rhythmic and there is little muscle movement. Blood pressure drops and growth and repair process can begin.

Stage 5

Up to about five times a night, we enter rapid eye movement (REM) sleep. The brain returns to normal levels, but we remain unconscious and have dreams of five to 30 minutes each.

The developing brain

Baby

In order to fit through the birth canal, human babies must be born well before their brains have finished developing, so their brains grow rapidly in their first years. Experiences prompt the development of new connections between nerves, and by the time a baby is two years old, it has 1.5 times as many synapses as an adult.

Infant

Support cells, known as glia, provide protection, insulation and nutrition for the brain's nerve cells. Throughout childhood, they continue to migrate and grow. During the first two to three years of a child's life, the insulating white matter of the still-developing brain begins to form.

Child

By the age of ten or 11, the rapid development of new connections in the brain has ended and a period of trimming and pruning begins. Instead of creating extra pathways, the brain focuses in on the most important, strengthening and insulating those that are used more often and losing ones that are no longer valuable.

Making memories

The human brain has an amazing capacity for retaining information

Sensory memory
The body is constantly bombarded by sensory signals and most incoming sensory information is retained for less than a second before it is forgotten.

Transfer
The hippocampus integrates incoming sensory information, collecting it together as a single experience. It works together with the cortex to prioritise which information to store and which to forget.

Short-term memory
Without concentrating too hard, short-term memory can hold around seven items for 20 to 30 seconds. Collecting information into discrete chunks, like splitting a phone number up into sections, can help the brain retain more.

Acoustic encoding
Short-term memory tends to be based on sound, also known as echoic memory. When remembering a phone number, it often helps to rehearse it vocally in your head.

Long-term memory
The hippocampus is essential for the transfer of memories from short- to long-term storage. Some of this memory consolidation happens in dreaming as the brain rehearses the day's activities.

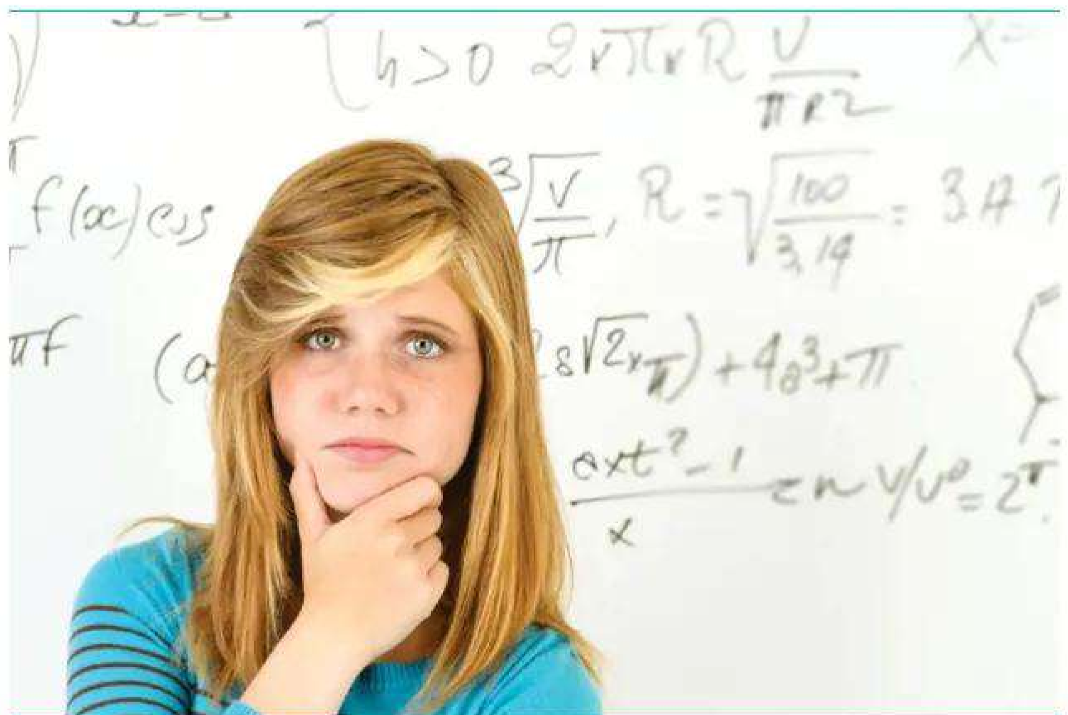
Semantic encoding
Instead of being linked to an audio memory, long-term memories tend to be stored more abstractly, by concept. Other memories are stored as sensory echoes, allowing entire experiences to be remembered and reconstructed.

Consolidation
Once the trace of a memory is formed, the pathway can be consolidated with use. The more often a synapse is used, the stronger it becomes.

Neuron changes
If a synapse is used repeatedly, it becomes increasingly sensitive to stimulation, producing more receptors and strengthening the connection.

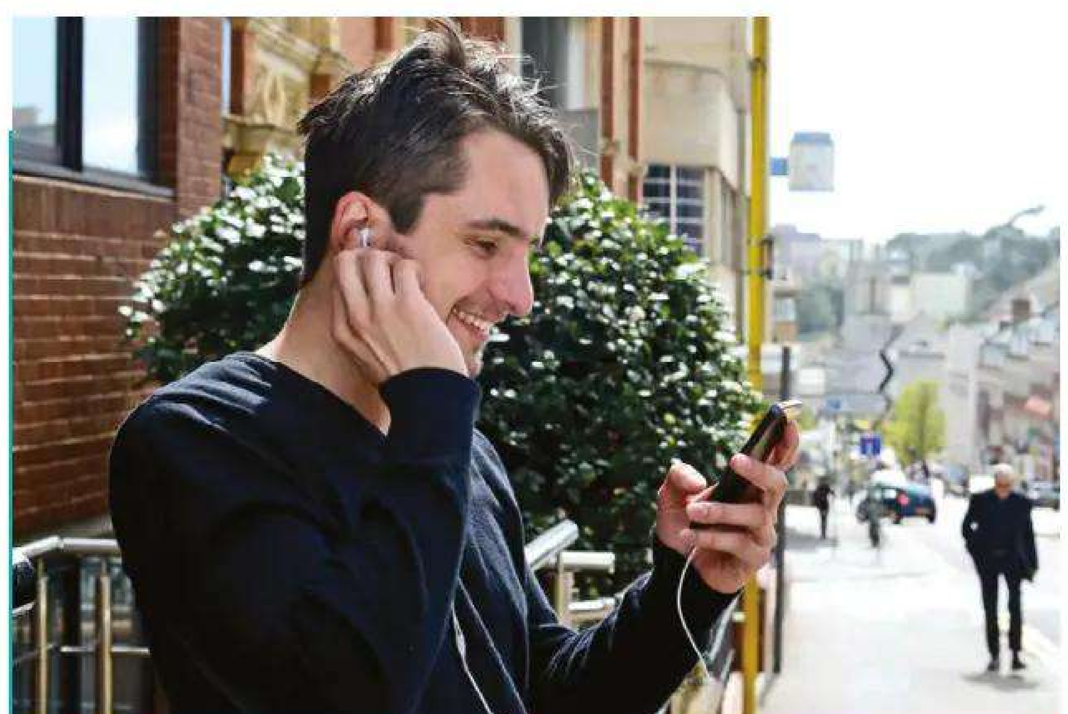
Recall
Human memory is associative; it works by linking pieces of information together. Memories are not stored as individual entities, but reconstructed using several different parts of the brain.

Implicit memory
These types of memories do not require conscious recall and are often based on motor skills. By repeating tasks, like riding a bike or playing the piano, pathways become automatic.



Explicit memory
Explicit memories are accessed consciously. They can be stored as episodes, linked to a specific event or place, or stored by category as more abstract knowledge.

Recognition
The brain is very good at making associations, and incoming information is compared to stored data, allowing us to quickly recall things we already know or have experienced before.



Association
Memories are rarely stored in isolation and one pathway is linked to others. Recognition and recall can both trigger other related memories.

Teenager
Trimming and adjusting the brain starts at the back and works forward, continuing into the teenage years. The prefrontal cortex, involved in planning, judgement and emotional control, is the last to be finished. Research also suggests that adolescents' body clocks are wired differently, so they naturally go to bed and wake up later.

Adult
Most growth and remodelling is complete by our early 20s, but new connections continue to form in the adult brain, albeit at a much slower rate than in children. Staying active and providing the brain with engagement and stimulation strengthens existing connections, and new pathways continue to form as we learn.

Old age
Damage to the brain cannot easily be repaired, so as it ages, signs of wear start to appear. Connections are lost as nerve cells wither, or as debris builds up between synapses, and gradually mental function can decline, leading to age-related illnesses like Alzheimer's disease and Parkinson's.

is going on inside the human brain, rebuilding the entire structure using this method will still take decades. The alternative is to simulate the brain, taking what we already know and using it as a scaffold to build the parts we have yet to study. By going back and testing the model brain against the real data, scientists can check that their simulation is working as it should.

Japan's K Computer is one of the fastest and most powerful in the world, and in 2014, 83,000 of its processors were combined in order to simulate one per cent of one second of human brain activity. This was a huge achievement, but it took the machine 40 minutes and barely represented a fraction of the power of the human brain.

The problem is that most modern computers are built on architecture completely different to the human brain. The brain is made up of processing cores, capable of specialising to perform highly specific tasks. They are less precise, but have much more flexibility, and most importantly, the capacity to learn. Memories are not stored in one particular place, and are instead distributed across the network. In contrast, modern computers use programs in order to decide what to do, and they store elements in a hierarchical memory.

In 2013, the European Commission funded the Human Brain Project with a grant of €1 billion (£800 million/$1.3 billion) in order to accomplish just that. This ambitious, ten-year endeavour aims to develop cutting-edge computational tools to assist in the understanding of brain function, bringing together the fragments from different disciplines and providing an unprecedented map of human brain activity. The Human Brain Project hopes to use this information to build a supercomputer capable of simulating the network that makes up the human brain. They estimate that it would take one laptop to simulate the activity of one neuron and are working closely with IBM to develop powerful neuromorphic supercomputers.

Neuromorphic chips are computer chips modelled on the architecture of the human brain. IBM released a chip modelled on the human brain in 2014. Known as the SyNAPSE chip, it has one million 'neurons' connected by 256 million 'synapses.' They are arranged into 4,096 'synaptic cores', which function in parallel with one another, just like the processing cores in the brain. Just like the brain, they operate on demand and can compensate if one core happens to fail.

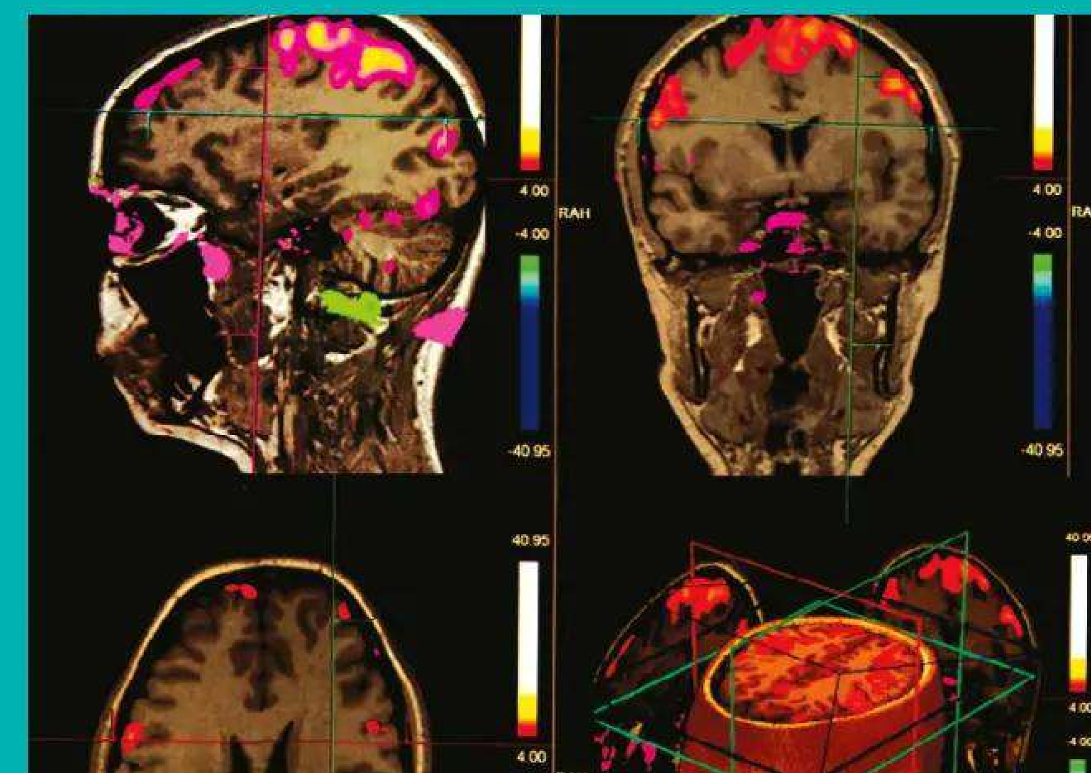
By feeding these computers with inputs that mimic biological signals, scientists can then

Imaging the brain

Take a look at the most common techniques used to study the living brain

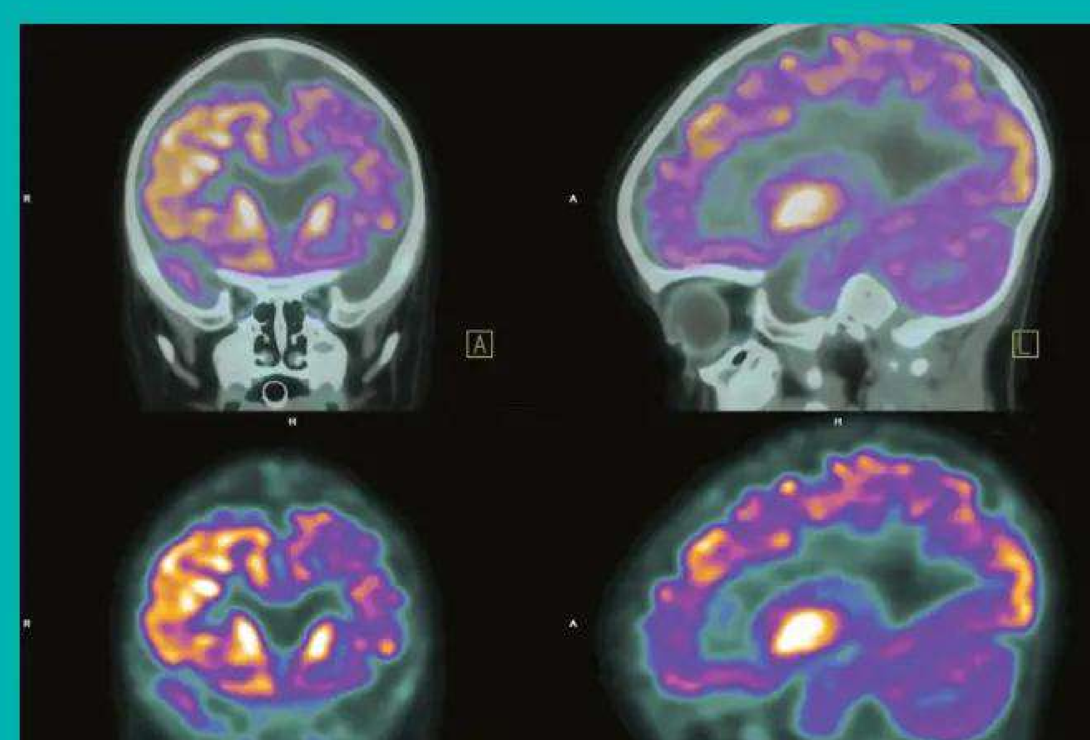
CT

Computed tomography (CT) scans use X-rays to build a three-dimensional image of the brain. The radiation travels at different speeds through different tissues, allowing a density map to be produced. It provides purely structural information and is useful for identifying tumours.



fMRI

Functional magnetic resonance imaging detects the amount of oxygen present in the blood, allowing brain activity to be mapped. When regions of the brain become more active, their demand for blood rises and they light up on the image. It captures a picture of the activity of the entire brain every two seconds.



PET

Positron emission tomography uses safe radioactive isotopes to measure brain activity. By labelling oxygen or sugar with radioactive tags, blood flow in the brain can be monitored. The tags emit low-energy radiation and as blood is diverted to active regions of the brain, the emissions pinpoint the locations.

EEG

Electroencephalograms take advantage of the electrical signals produced by nerves to produce a map of brain function. Electrodes placed on the scalp are able to detect the patterns of nerve activity beneath the surface. This technique comes in particularly handy for sleep studies.

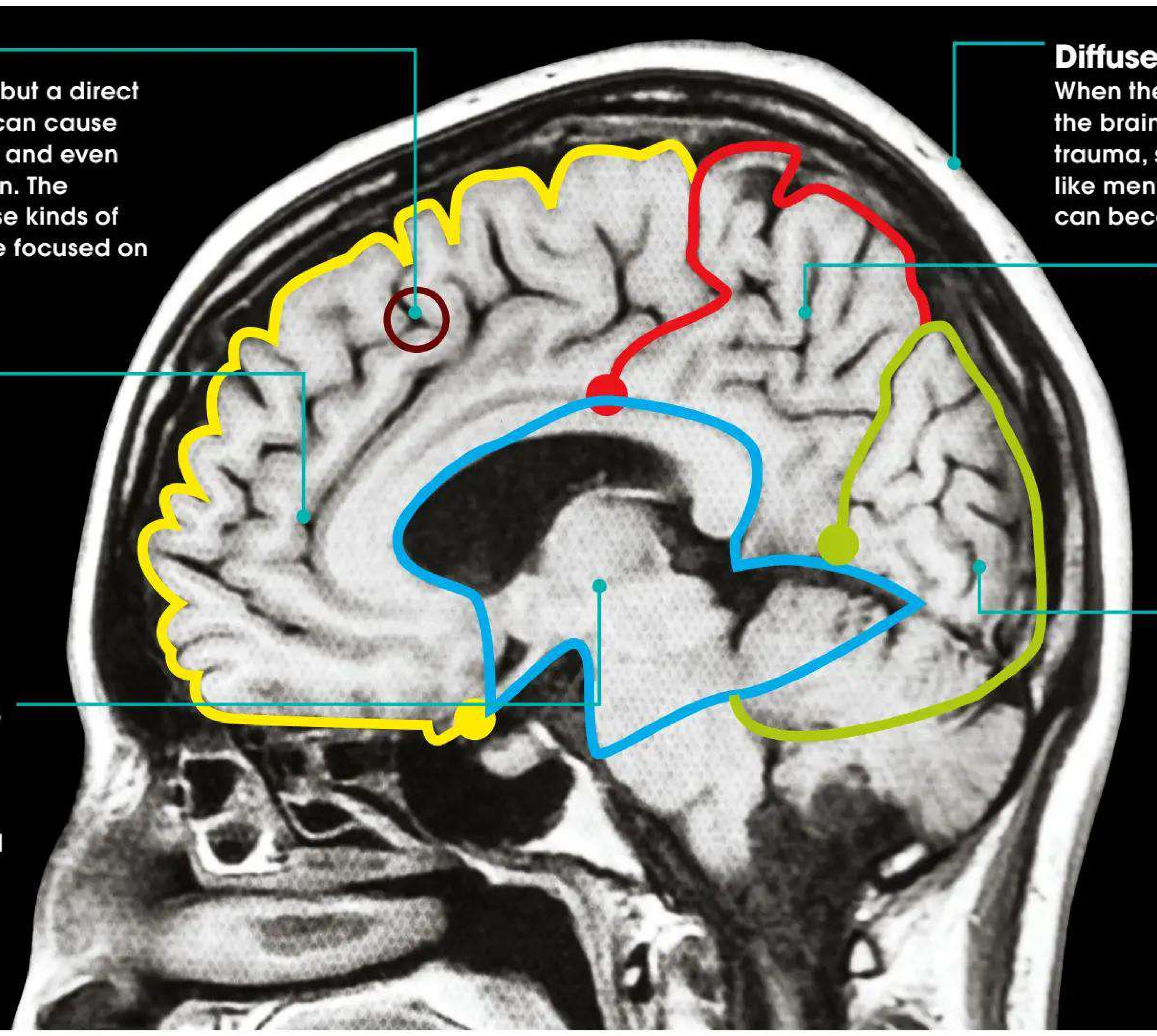
Brain damage

Different injuries affect the brain in different ways

Severe
If the injury is severe, the patient is no longer able to respond to sensory stimulation. Their eyes remain closed and there is no response at all to verbal cues.

Moderate
When brain injury is more severe, verbal communication starts to break down and patients no longer respond normally to pain.

Mild
With mild brain injury, patients may be confused, but they remain aware, conscious and conversational.



Focal injury
The skull is strong, but a direct blow to the head can cause bruising, bleeding and even penetrate the brain. The damage from these kinds of injuries tends to be focused on one location.

Frontal lobe
Damage to the frontal lobes affects higher cognitive functions like reasoning, social interactions and emotional regulation.

Temporal lobe
Damage to the temporal lobes can interrupt the formation of visual and long-term memories, as well as processing incoming sensory information.

Diffuse injury
When the blood supply to the brain is interrupted, by trauma, stroke, or infections like meningitis, large areas can become damaged.

Parietal lobe
Damage to the parietal lobes affects spatial awareness and the ability to understand the three-dimensional environment, either visually or by touch.

Occipital lobe
The occipital lobe is responsible for vision, so injury to the back of the head can result in visual problems, ranging from temporary blurring through to 'seeing stars' and to permanent blindness.

"The brain is made up of processing cores, capable of specialising to perform highly specific tasks"

examine the electrical activity and can see where information is being processed and stored. The project is a collaboration between over 100 institutions in 24 countries.

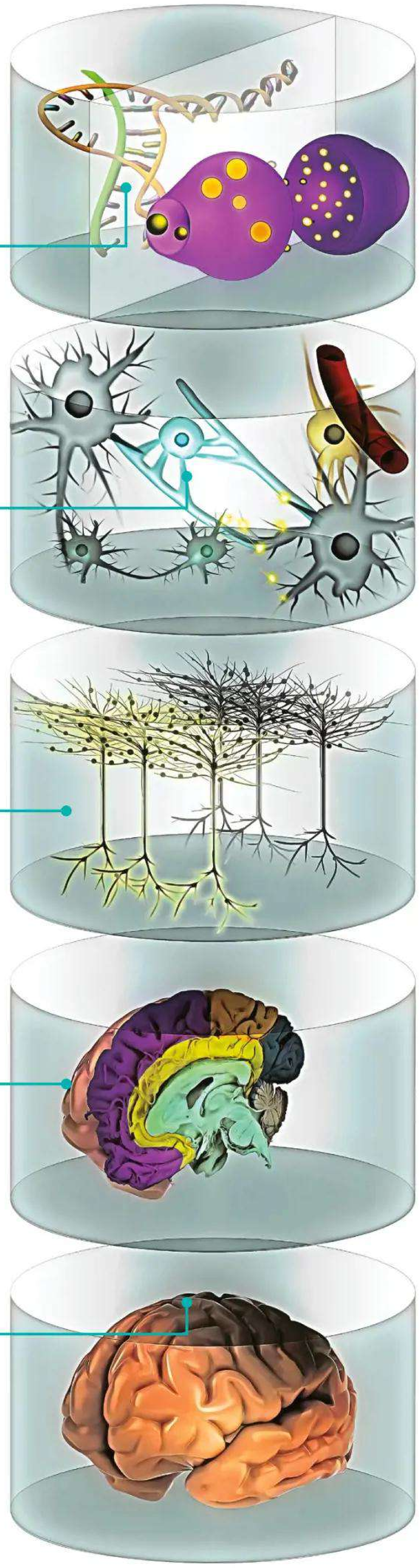
New technology is the key to modelling a structure as complex as the human brain, and other international efforts are also in place to provide new technology. In 2013, US President Barack Obama announced the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) initiative. The NIH (National Institutes of Health) allocated £24 million ($40 million) in 2014 to develop new technologies to find the best way to understand the brain. In order to break the brain down and rebuild it accurately, the project combined silicon-based techniques and advancements in stem-cell biology, brain imaging and medical drug development.

Cutting-edge neuroscience

The human brain is one of the most complex structures in the known universe and understanding how it works is an enormous scientific undertaking. Modern neuroscience brings together experts from a huge array of fields and scientists are finally beginning to untangle the many mysteries of the human brain

Building a brain

Large-scale projects aim to simulate the human brain at every level



DNA and neurotransmitters

At the molecular level, scientists are able to manipulate the 3D structures of proteins using computer programmes, and to model the effects that changes might have. Such techniques are hugely useful in drug design.

Nerves and support cells

In order to gain a proper understanding of how the brain functions, many scientists advocate a bottom-up approach. By creating digital neurons based on the underlying rules and principles of biology, it is hoped that the complex network of the brain can be simulated.

Neural pathways

Some projects aim to map all of the connections in the human brain, generating a 3D representation of the intricate wiring. Others aim to simulate the process, allowing the computer to make its own connections based on biological rules.

Lobes and structures

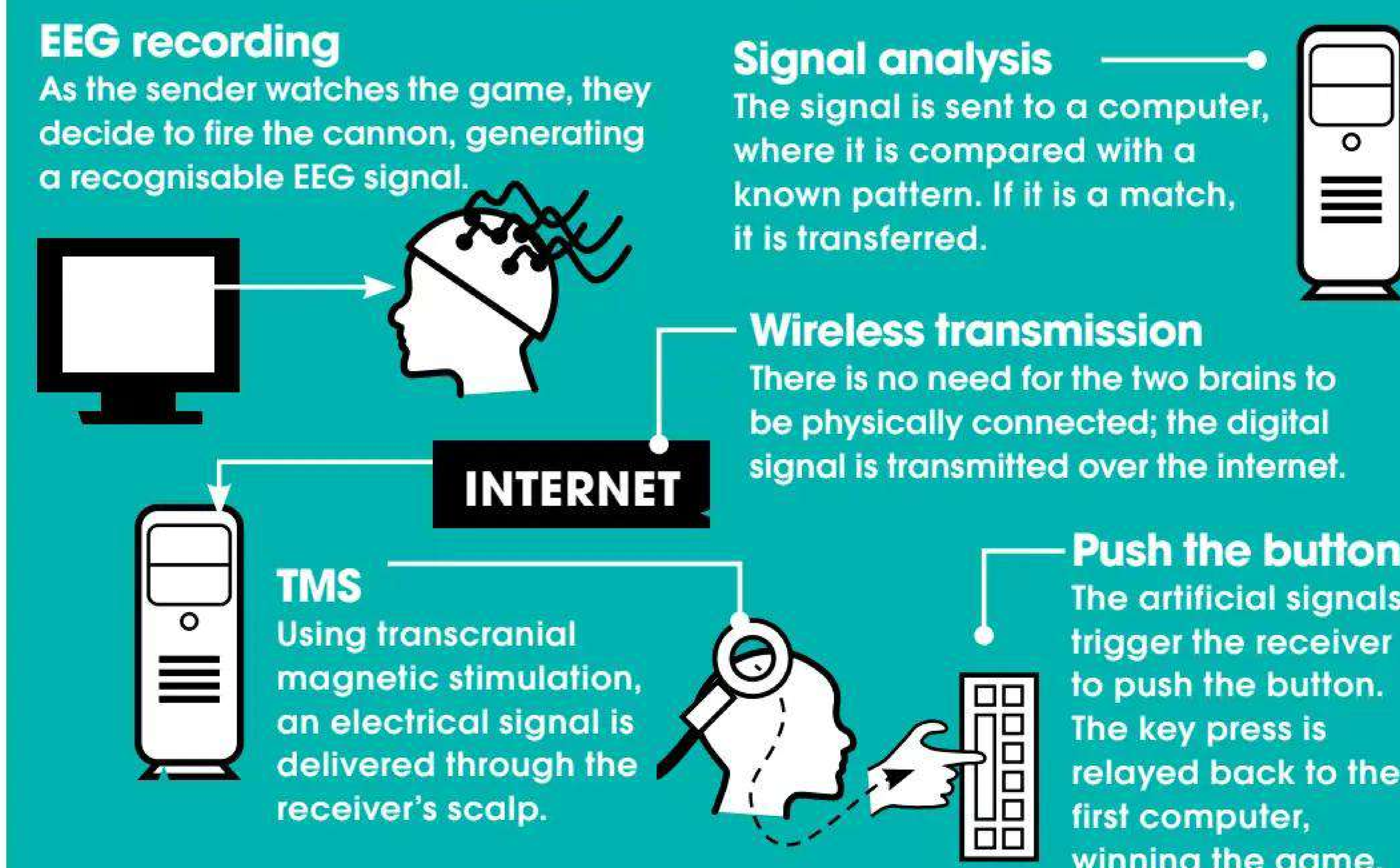
Simulations will allow information about different structures in the brain to be integrated, enabling scientists to more closely examine the interactions between different areas, or even to remove one region and study it in isolation.

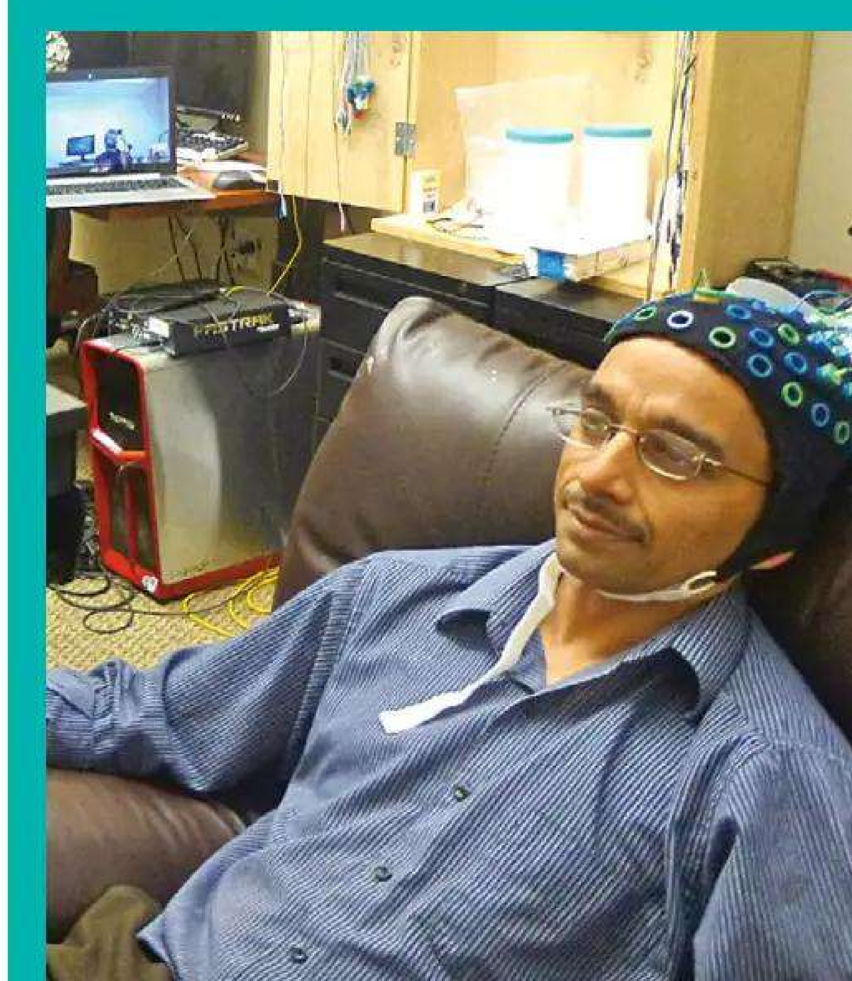
Whole brain

In 2013, the K Computer in Japan carried out one second of simulated human brain activity. With 705,024 processor cores, it took the machine 40 minutes to simulate a network just one per cent of the size of the human brain. Advanced processors due in the next ten years will increase this capability significantly.

How mind control works

Simple equipment and complex computer programming allow our thoughts to be transmitted over the internet





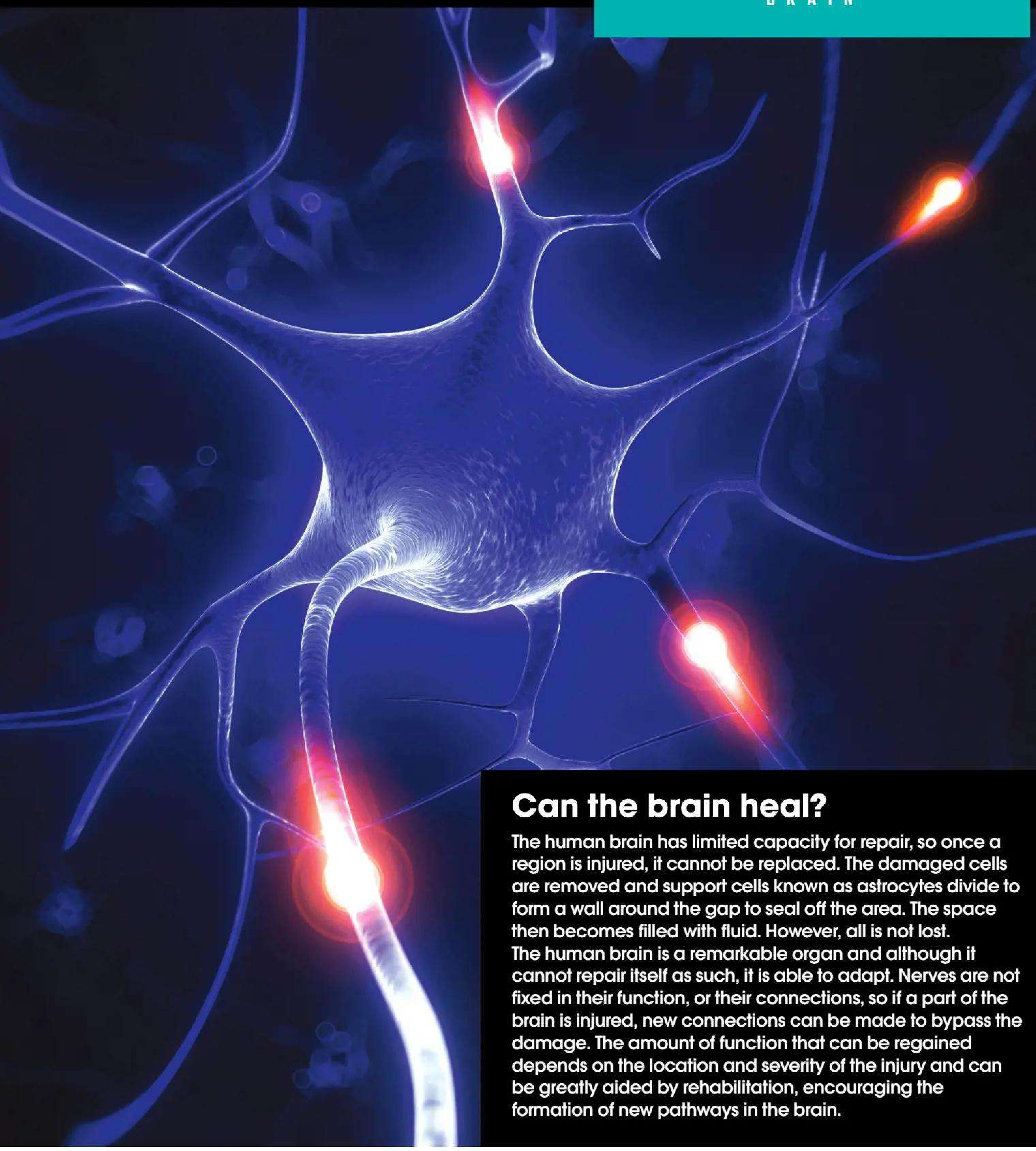
Mind control

In a groundbreaking experiment in 2013, researchers at the University of Washington successfully linked two human brains together and proved their principle with a video game.

The city is under attack by pirates, where player one, the sender, must intercept their rockets. They can see the screen and are armed with a cannon, but they do not have a keyboard and cannot press 'fire'. Player two, the receiver, is sitting in another room; he cannot see the game, but he does have a keyboard. Player one thinks about firing the cannon, and fractions of a second later, player two pushes the button, saving the city and winning the game.

Player one was wired up to an electroencephalogram (EEG) and his brain activity was being monitored. When he was thinking about pressing the button, there was a characteristic signal in the 'mu band' of the EEG, triggering the program to send a wireless signal to player two.

Player two was wearing a specially designed coil on his scalp that generated a magnetic field, positioned over the part of the brain that controls contraction in the right hand. The signal from player one was converted into magnetic stimulation, which in turn triggered electrical activity in the brain, causing player two to involuntarily fire the cannon.



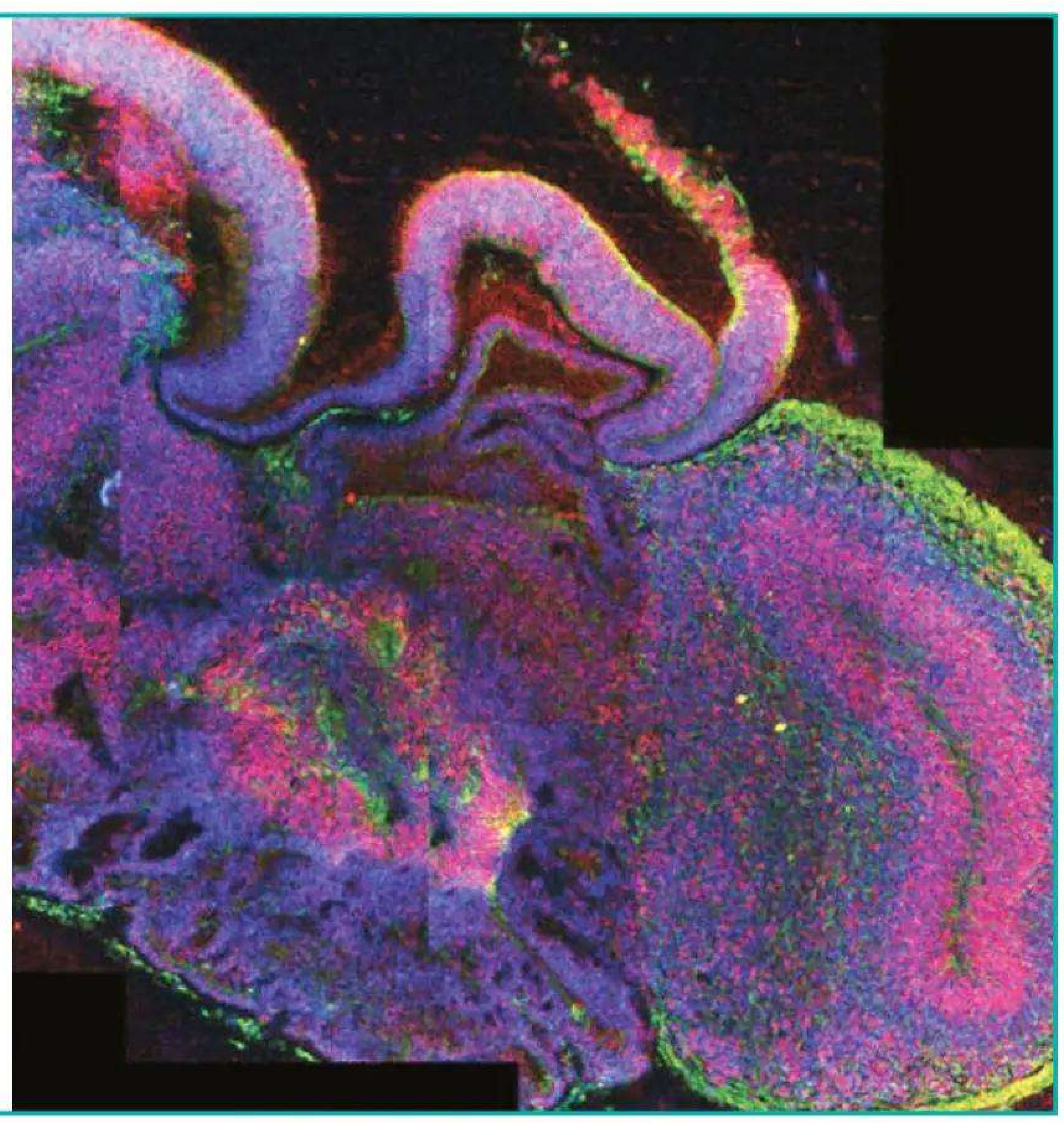
Can the brain heal?

The human brain has limited capacity for repair, so once a region is injured, it cannot be replaced. The damaged cells are removed and support cells known as astrocytes divide to form a wall around the gap to seal off the area. The space then becomes filled with fluid. However, all is not lost. The human brain is a remarkable organ and although it cannot repair itself as such, it is able to adapt. Nerves are not fixed in their function, or their connections, so if a part of the brain is injured, new connections can be made to bypass the damage. The amount of function that can be regained depends on the location and severity of the injury and can be greatly aided by rehabilitation, encouraging the formation of new pathways in the brain.

Growing a brain

In 2013, scientists at the Austrian Academy of Sciences achieved something incredible; they grew part of a human brain in a Petri dish. Using a combination of embryonic stem cells and stem cells taken from adult skin, the team recreated the neuroectoderm, the embryonic structure that goes on to form the brain and the spinal cord.

The cells were put in three-dimensional scaffolds to give them something to grow around, and then given nutrients and oxygen and allowed to develop. Amazingly, the structures organised themselves into something resembling the brain of a nine-week-old foetus. Some contained the pigmented cells of a retina, others developed a cortex and some even had a hippocampus. These mini-brains are about the size of a pea, and incapable of conscious thought, but could provide a valuable tool for researchers.



"Researchers are using electricity to selectively erase memories"

The practical applications of this future technology are incredible, but we are already able to interface with the brain in more ways than ever before. sLight-sensitive retinal implants can restore sight to the blind by sending electrical signals to the optic nerve, while auditory brainstem implants communicate sound signals directly to the brain in patients who are profoundly deaf.

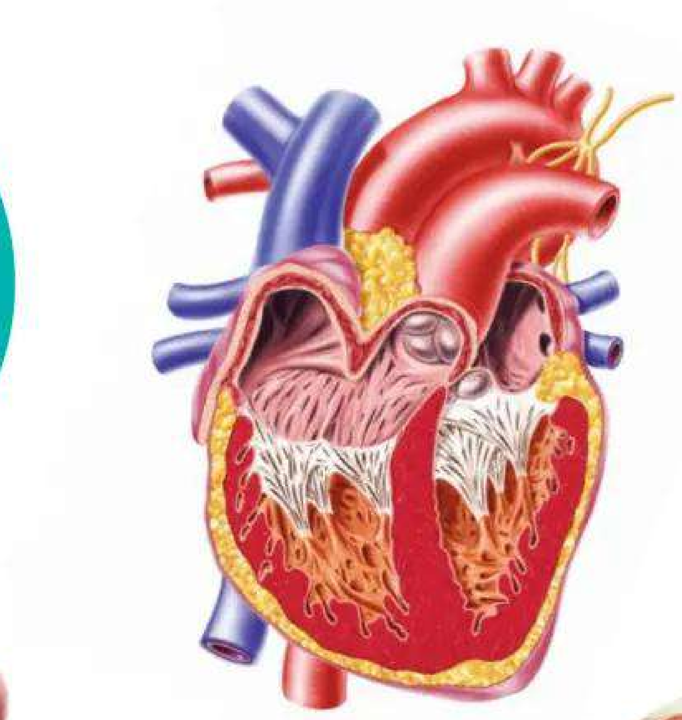
However, one of the most incredible technological developments of all is the BrainGate system, first revealed in 2006 and now undergoing clinical trials. The technology uses a sensor implanted on the motor cortex of the brain to pick up electrical signals generated when the patient thinks about moving. These signals are then decoded by a computer program and sent to a prosthetic limb. By carefully training the program to recognise specific signals, patients are able to move their bionic hands using just the power of their brains.

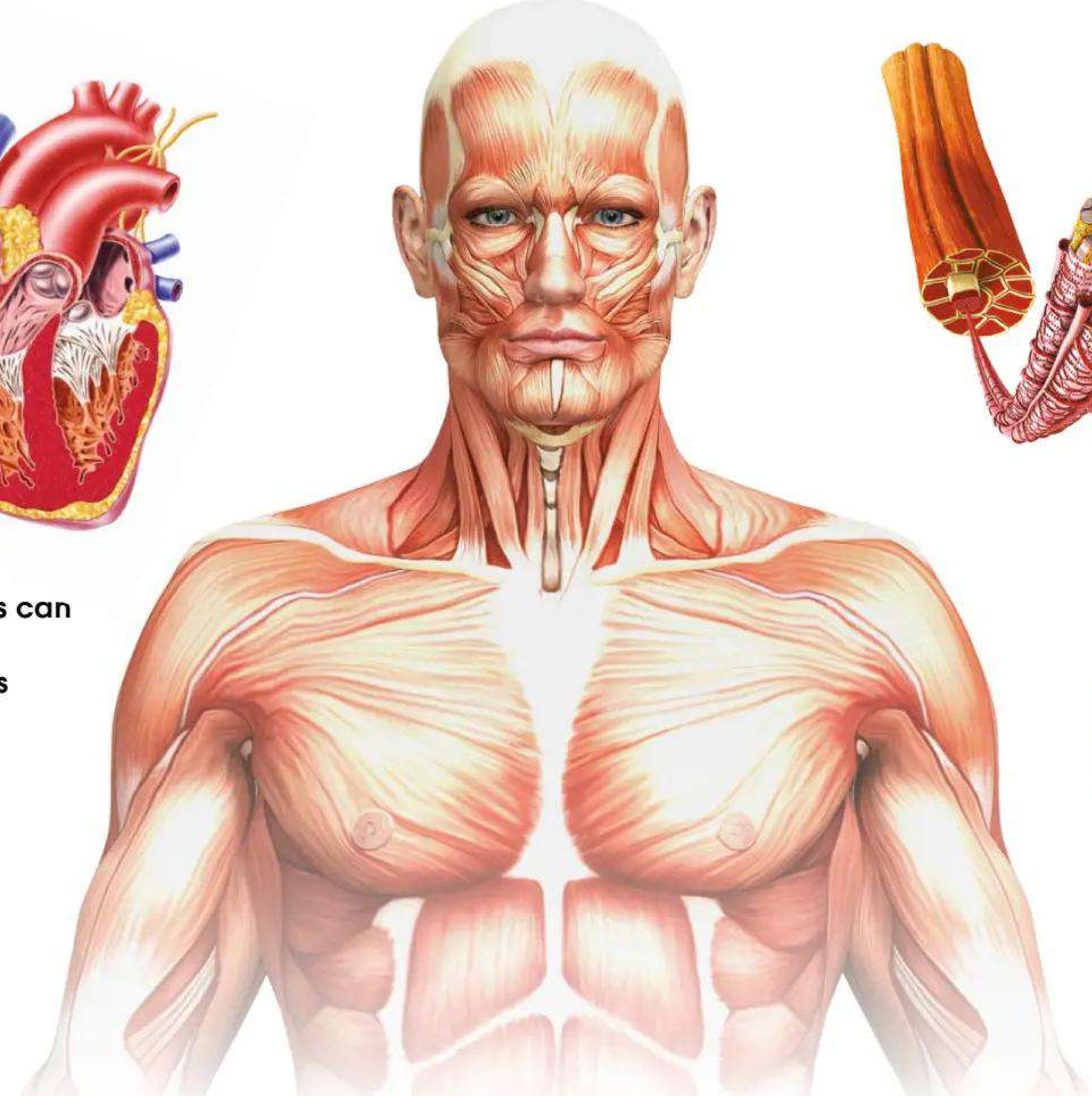
Taking electrical brain interfaces one step further, at the University of California, San Diego, researchers are using electricity to selectively erase memories. They have shown that by using particular frequencies of electrical pulses they can produce changes in the nerve cells in the brains of rats, making them forget traumatising experiences in their past.

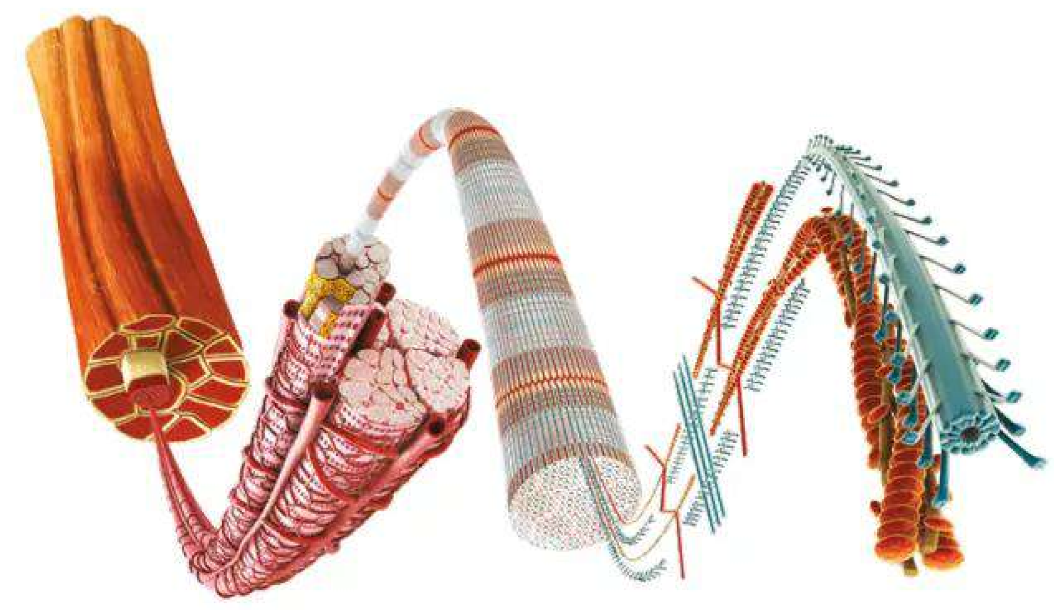
As we continue to learn more about the connections in the brain, the possibilities for interacting with it will only continue to increase. The field of neuroscience is advancing faster than ever before, and huge international collaborations, like the Human Brain Project and the BRAIN initiative, are bringing mountains of research data together, creating resources that will revolutionise the field of neuroscience.

The puzzle of the human brain has been vexing scientists, doctors, and philosophers for thousands of years and understanding how it works is perhaps the most challenging problem in the history of science. However, with a combination of powerful new technology and international collaboration, the complexity of this mass of neurons is starting to unravel. Very soon, we might even be able to rebuild a functioning digital brain from the bottom up.

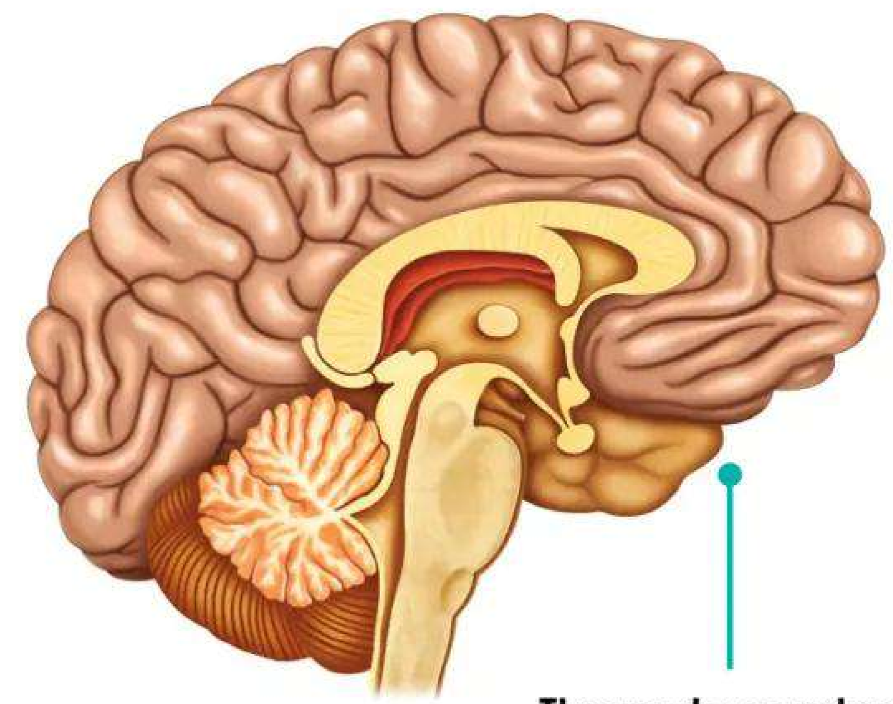
Making connections
The hyoid in the neck is the only bone that isn't connected to another bone



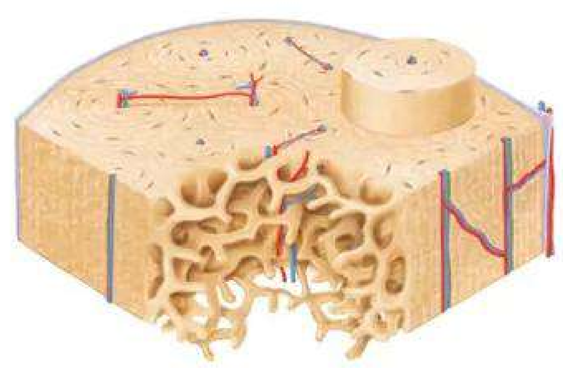




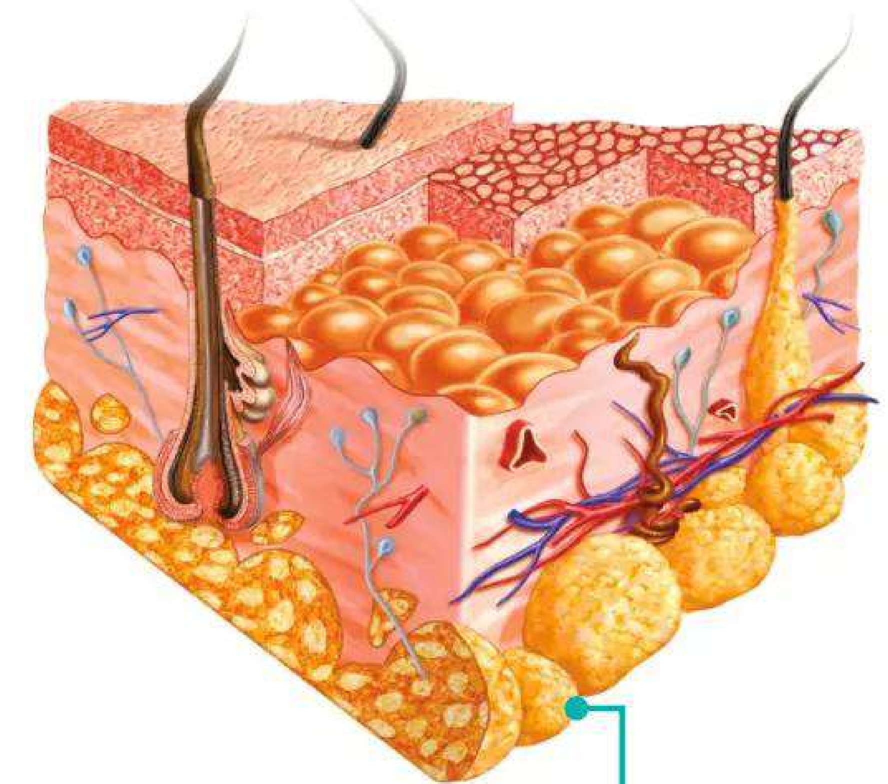
Red blood cells can live for up to 120 days



The male cerebral cortex has about 23 billion neurons



The body comprises around 75 trillion cells



1cm² of skin can contain 70cm of blood vessels

The human body

Journey inside the body to discover just what we are made of

The human body is composed of an estimated 7 octillion atoms, making up over 75 trillion cells. At the atomic level, the human body comprises about 60 elements, but the function of many of them is unknown. In fact, 99 per cent of the human body is made from just six elements.

Like all other life discovered to date, we are carbon-based; the biomolecules that make up our bodies are constructed using frameworks of carbon atoms. Carbon is almost unique among the elements; it is small in size and can make four covalent bonds to other atoms, allowing it to form the backbone of key molecules that make up the human body. The bonds are strong enough to hold the molecules in a stable structure, but not so strong that they can't be taken apart again, allowing the body to break and reform molecules over and over.

Calcium is the most abundant mineral in the human body, important for the regulation of protein production and activity.

Complex cascades of chemical reactions occur within the gel-like cytoplasm and organelles of cells – tiny structures that perform specific functions within a cell. Phosphorus is used to make adenosine triphosphate (ATP), which has high-energy phosphate bonds that can be broken in order to power cellular processes; ATP is essentially our cells' fuel. Cells are coated in receptors and respond rapidly to environmental changes, communicating via chemical signals and electrical impulses. During embryonic development, chemical gradients tell developing cells where to go, and what cell type to become, resulting in a new person.

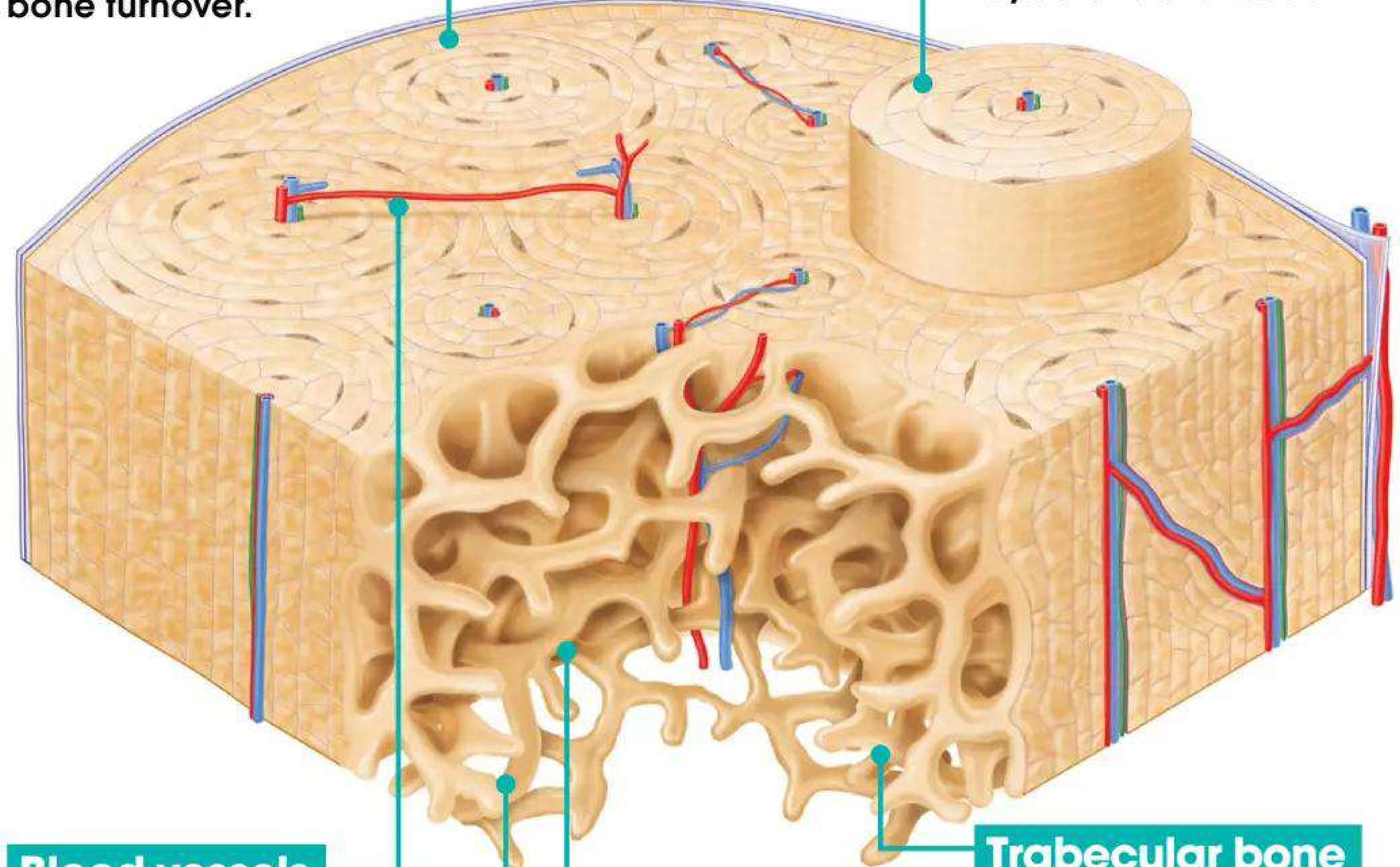
Interestingly, the majority of the cells in the human body are not human. Microbes make up between one and three per cent of our body mass and are hugely important for our proper functioning. They have 8 million different coding genes for making proteins, compared to less than 30,000 in the human genome.

The bacteria that live in our digestive system provide essential support, too; they ferment undigested carbohydrates, allowing us to access energy we couldn't otherwise digest, and they have a role in the production of biotin and vitamin K. Their presence in the gut also prevents 'bad' bacteria from taking hold and making us unwell. Even more unusually, at least eight per cent of the human genome is viral in origin. Retroviruses are able to insert their DNA into our chromosomes, and at several points in human evolution, genes that started out in viruses have become permanently entwined with our own genetic information.

How many hairs?
A human head has an average of 100,000 to 150,000 hairs

The structure of bones

The long bones of the body, such as the femur (thighbone), contain two distinct types of bone



Osteocyte
The cells that form the bone matrix eventually become trapped in it. They help to regulate bone turnover.

Cortical bone
The tough outer layer of bones contains densely packed cylindrical structures – osteons – formed from concentric layers of bone tissue.

Blood vessels
Bone is a metabolically active tissue and a good blood supply allows for mineral exchange.

Trabecular bone
Within the ends of long bones is a looser, honeycomb structure, where calcium is released from storage as required.

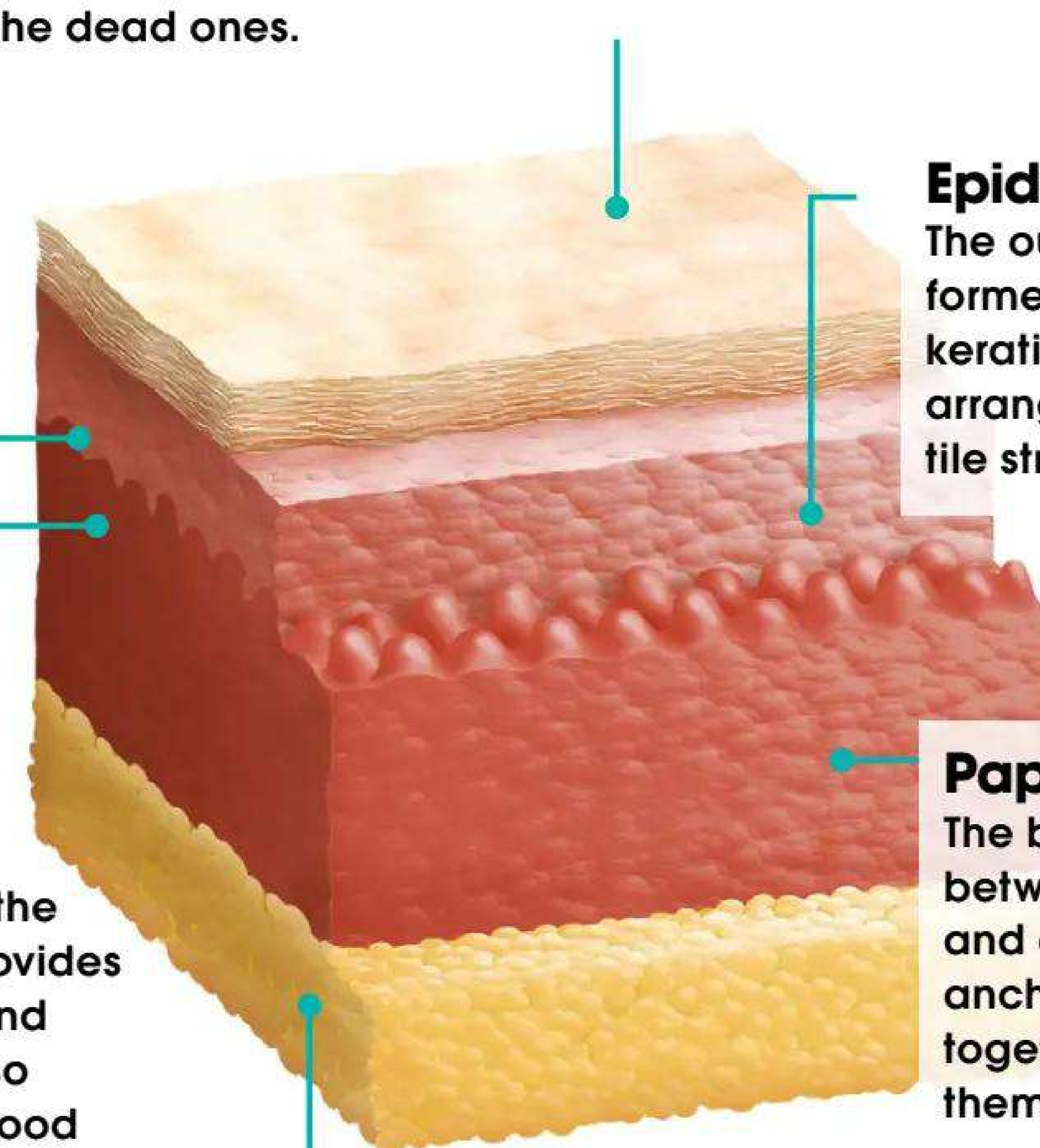
Osteoblast
Osteoblasts make new bone, producing the collagen scaffold and laying down minerals.

Osteoclast
Osteoclasts are related to cells of the immune system and digest old bone to release minerals and allow for remodelling.

Beneath the skin

Skin has several layers with a unique function.

Largest organ of the body
The skin of a human adult measures two square metres (22 square feet)



Stem cells
A layer of stem cells at the base of the epidermis divides to form new skin cells, which push upwards to replace the dead ones.

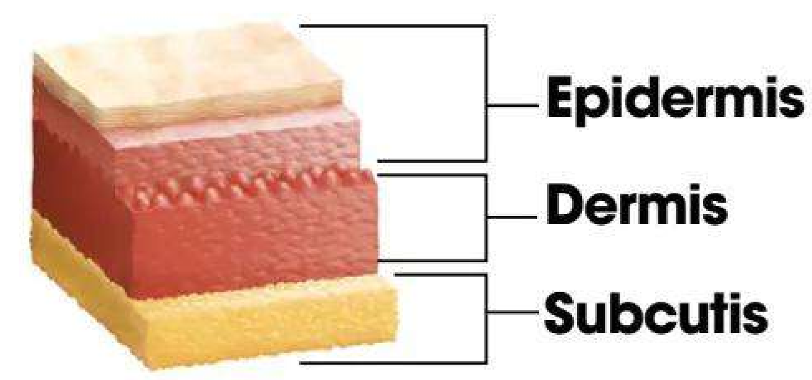
Cornified layer
The very outer layer of the skin consists entirely of flattened, dead cells. These provide a protective barrier.

Epidermis
The outer layer of skin is formed of cells known as keratinocytes. These cells arrange in a multilayered tile structure.

Dermis
Connective tissue below the epidermis provides cushioning and support. It also carries the blood vessels that supply the skin cells.

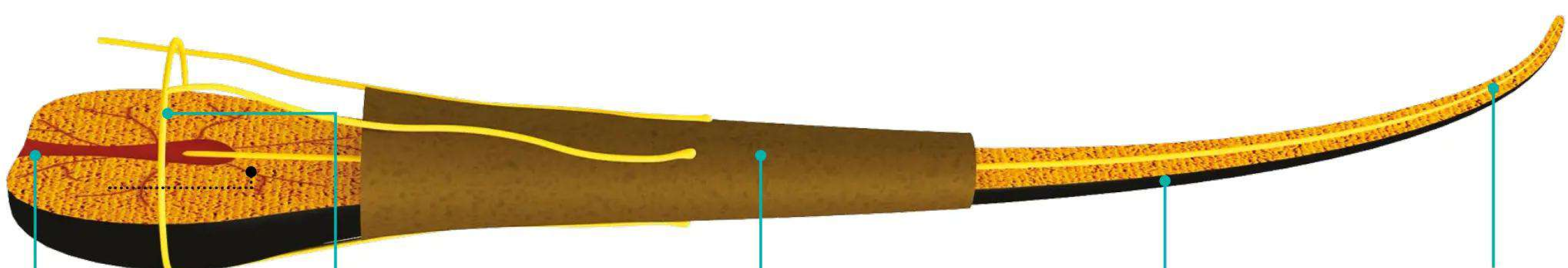
Papillae
The bumpy structure between the dermis and epidermis helps to anchor the two layers together, preventing them from slipping.

Fat
A layer of subcutaneous adipose tissue provides cushioning and insulation, as well as energy storage.



Hair under the microscope

A strand of hair can be divided into three distinct regions



Papillae
Blood vessels supply nutrients to the cells of the matrix and root.

Matrix
Cells of the matrix divide to produce new hair.

Cuticle
The outside of the hair is made of layers of flattened cells that overlap, protecting the hair.

Cortex
The body of the hair is made from coiled strands of keratin. Melanin granules within the cortex lend it its colour.

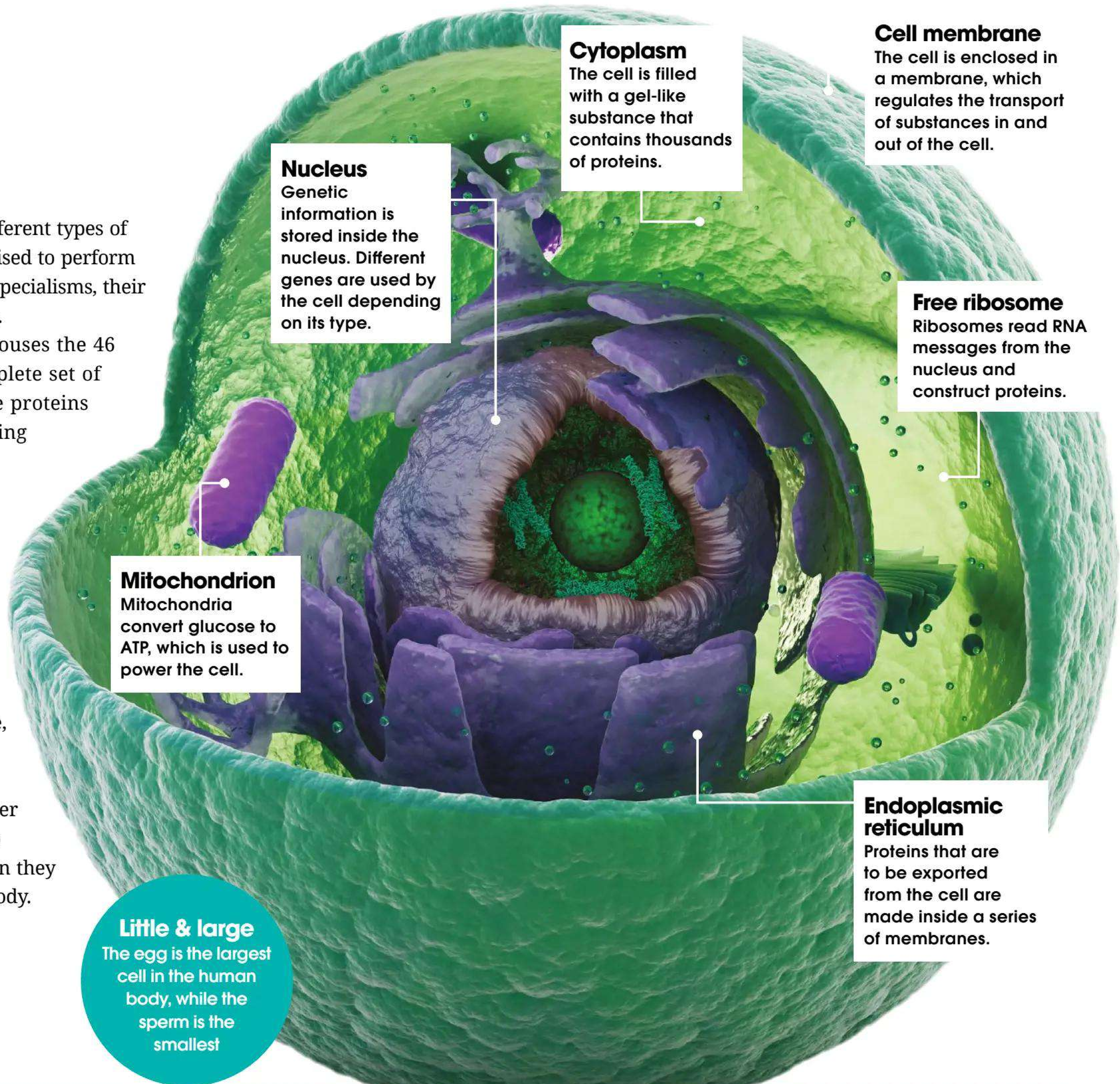
Medulla
An open, unstructured core runs up the centre of the hair.

Close up with cells

There are thought to be over 200 different types of cell in the human body, each specialised to perform a particular function. Despite these specialisms, their basic underlying biology is the same.

Cells contain a nucleus, which houses the 46 chromosomes, containing the complete set of instructions to synthesise all of the proteins found in the human body. Depending the type of cell, different genes switched on and off, determining proteins the cell will produce.

Proteins for use inside the cell are created on ribosomes in cytoplasm. The ribosomes read genetic message and assemble corresponding protein using amino as building blocks. Proteins to be exported from the cell – for example, antibodies or digestive enzymes are constructed within a series membranes. Here they gain a number of modifications that enable them to survive the harsh environment when they leave the cell to travel around the body.



Little & large
The egg is the largest cell in the human body, while the sperm is the smallest

Key cells of the body

Blood and immune cells

Type: Blood

The cells of the blood, including red blood cells and the white blood cells of the immune system, are all produced in the bone marrow. Red blood cells lack a nucleus, enabling them to pack more of the oxygen-carrying protein, haemoglobin, into their cytoplasm.

Epithelial cells

Type: Skin and membranes

The cells that cover our bodies and line our body cavities form junctions with one another. Using proteins anchored between their membranes, they join to create strong barriers to protect the body.

Contractile cells

Type: Muscle

These cells contain a protein ratchet system, which enables them to contract. Actin and myosin form long strands, which slide past one another, pulling the edges of the cell together.

Nerve cells

Type: Brain and nerves

Nerve cells have specialised membranes, which use molecular pumps to maintain an electrochemical gradient; this allows them to transmit electrical signals. Nerves function more efficiently if they are insulated and many nerve cells are covered by a fatty sheath of myelin.

Stem cells

Type: Undifferentiated

Stem cells are ones that have not yet committed to a particular specialism. They are found in many locations and provide a replicating reservoir of cells that can be used to maintain and repair the body.

Extracellular matrix cells

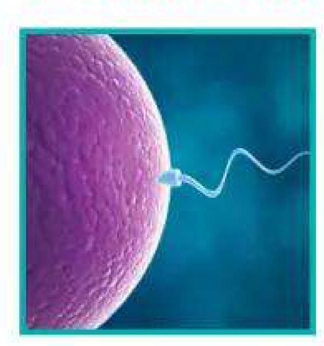
Type: Connective tissue

The cells of the body are supported by networks of fibres including collagen and elastin. These are generated by extracellular matrix cells like fibroblasts, which produce and secrete precursor components that then assemble into the fibres that make up the matrix.

Endocrine cells

Type: Hormones

These cells generate hormones and release them locally or into the bloodstream. Their hormone-releasing activity is controlled by neurotransmitters sent from local nerves, or by other chemical messengers, which bind to receptors that are on the cell surface.



Germ cell

Type: Reproductive

Sperm and egg cells have just one copy of each chromosome and are formed by a special type of cell division called meiosis. When sperm and egg combine, the resulting cell has a full set of 46 chromosomes.

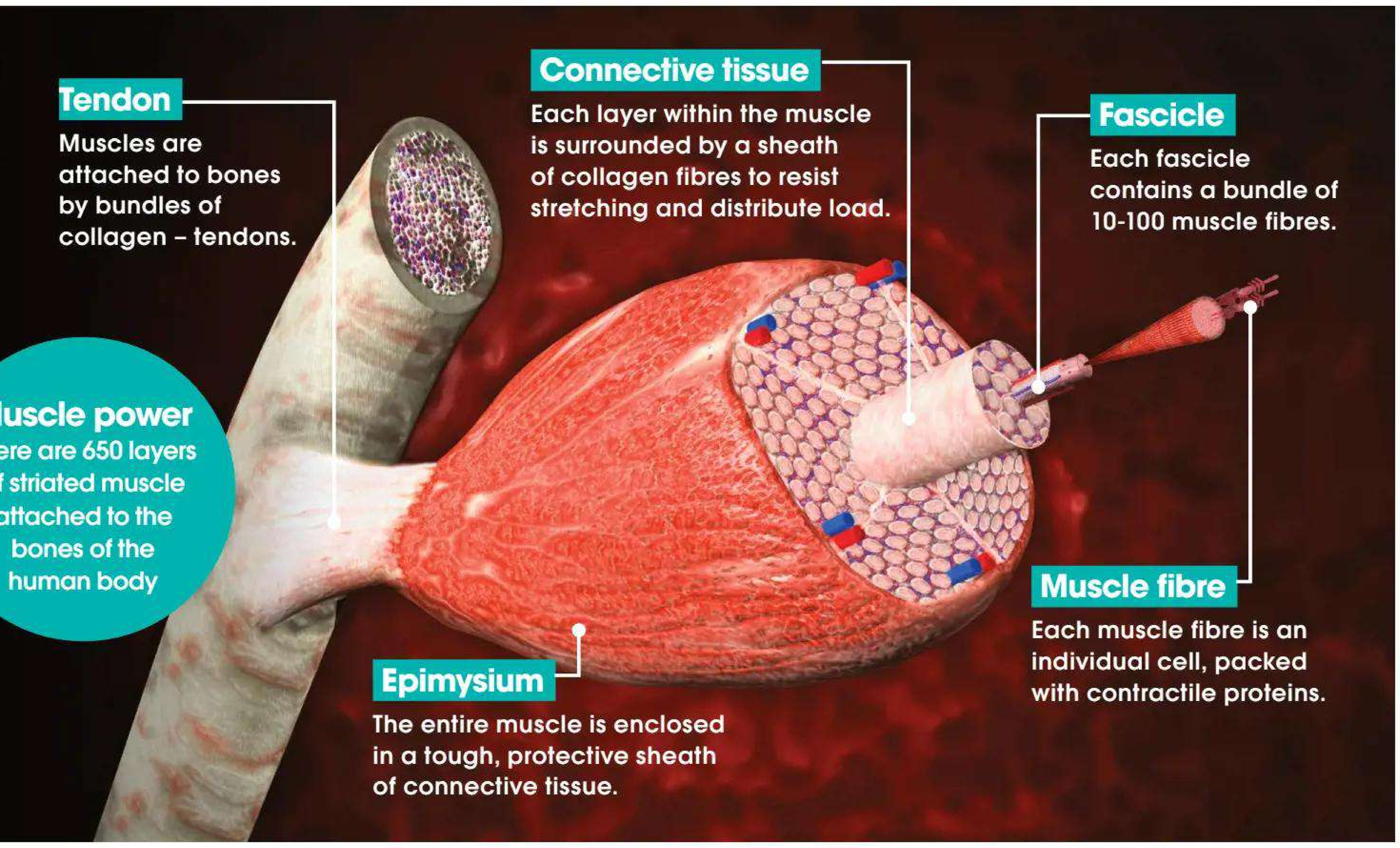
Muscle and movement

Skeletal muscle is responsible for moving the skeleton. It is composed of bundles of muscle fibres, sheathed in a strong collagen matrix, which extends into tendons that attach to the bone.

Within each muscle fibre is a molecular ratchet system made from the proteins actin and myosin. As the protein filaments slide past one another, the muscle fibre contracts lengthways and the fibre shortens.

Muscle fibres can be categorised as being either fast or slow twitch. Fast-twitch fibres use high-speed anaerobic respiration to produce rapid movements, but fatigue quickly. In contrast, slow-twitch fibres use sustainable aerobic respiration to produce slower movement for longer periods of time.

The proportion of slow- and fast-twitch fibres affects athletic performance – for instance, long-distance runners have a higher proportion of slow-twitch fibres than sprinters. Whether muscle fibres can change from one to another is under investigation.

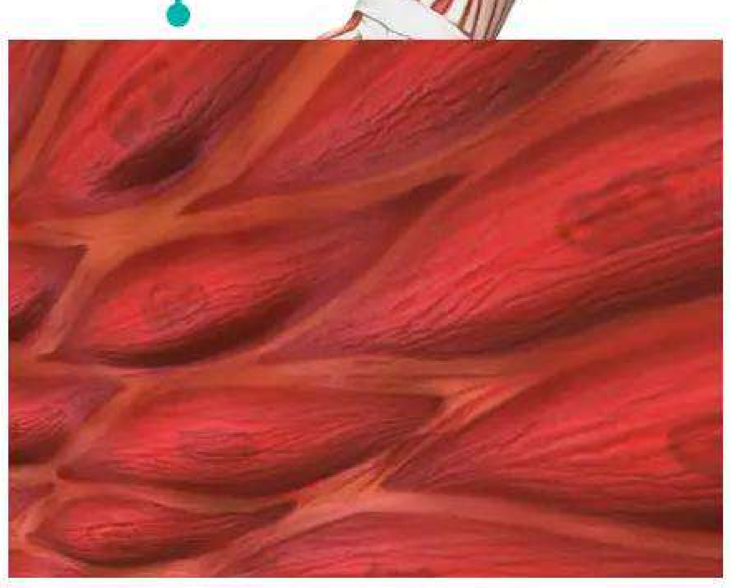


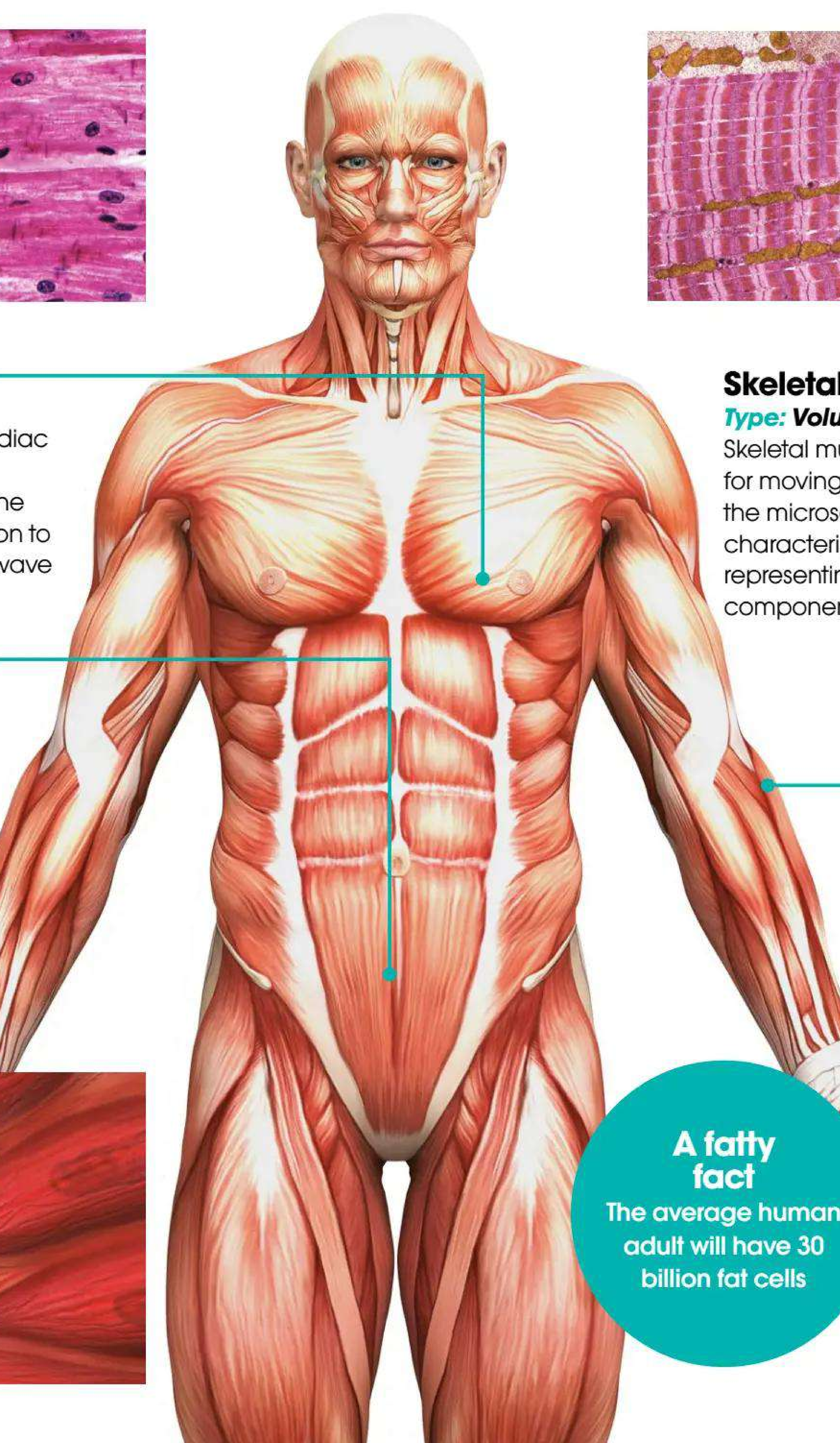
Muscle power
There are 650 layers of striated muscle attached to the bones of the human body

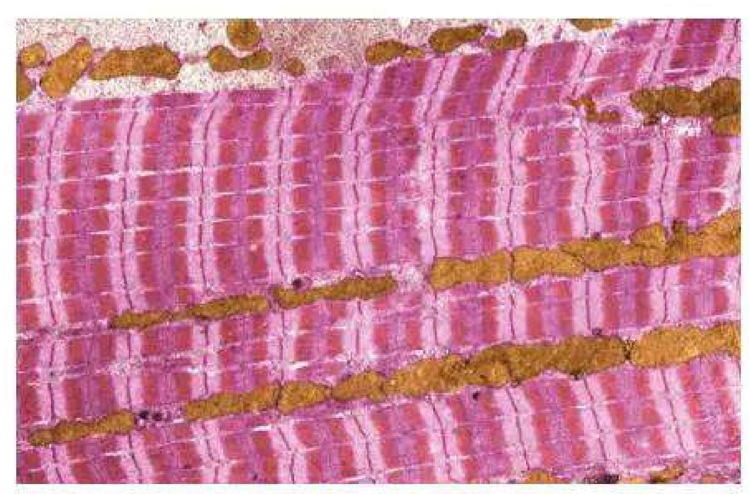
Types of muscle

Cardiac muscle
***Type:* Heart**
Like skeletal muscle, cardiac muscle is striated. Connections between the cells allow the contraction to pass in a co-ordinated wave across the heart.

Smooth muscle
***Type:* Involuntary**
The smooth muscle that lines internal structures is more elastic than skeletal muscle, allowing the intestines and bladder, etc, to contract even when stretched.







Skeletal muscle
***Type:* Voluntary**
Skeletal muscle is responsible for moving the skeleton. Under the microscope it has characteristic striped bands, representing the contractile components within the cells.

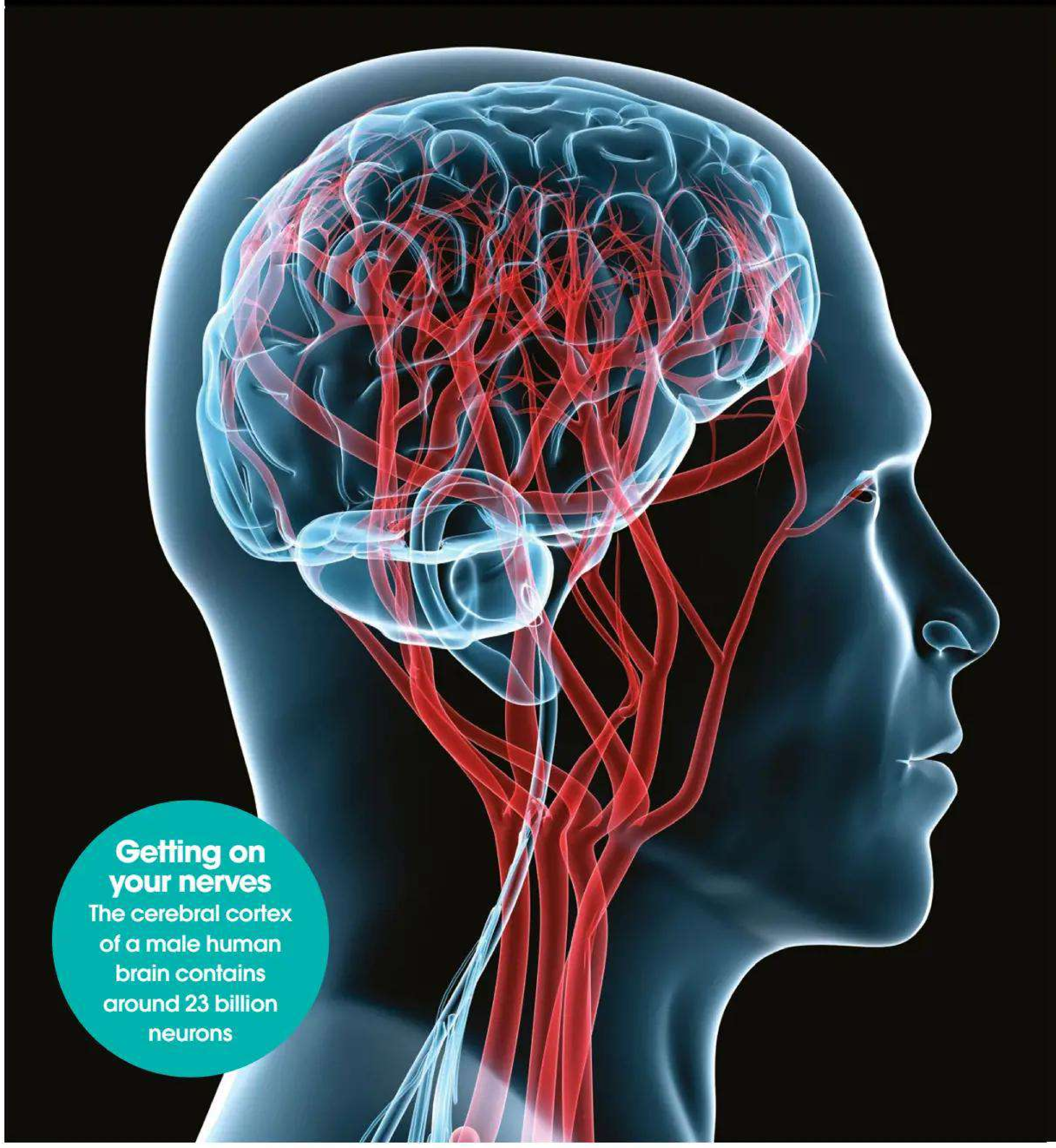
A fatty fact
The average human adult will have 30 billion fat cells

Why our bodies need a little fat

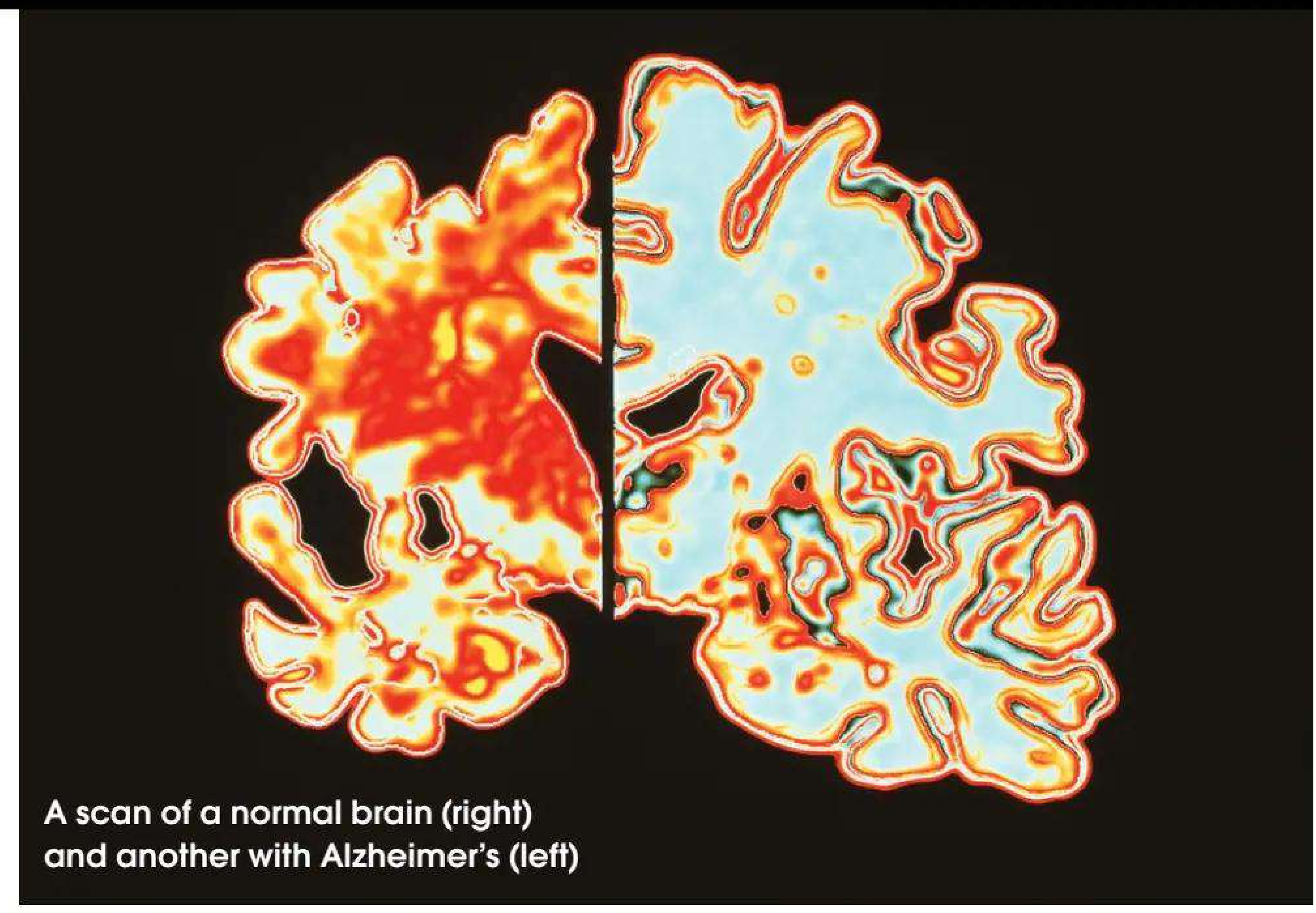
Adipose tissue provides the body with an energy reserve and also acts as a shock absorber – particularly on the soles of the feet. The fat cells – also known as adipocytes – contain a large lipid droplet, which takes up almost their entire volume, while their nuclei and other organelles are squashed on the perimeter.

Adipocytes are not just used as storage sacks, though. They have important metabolic and hormonal duties, too, including involvement in the production of oestrogen.

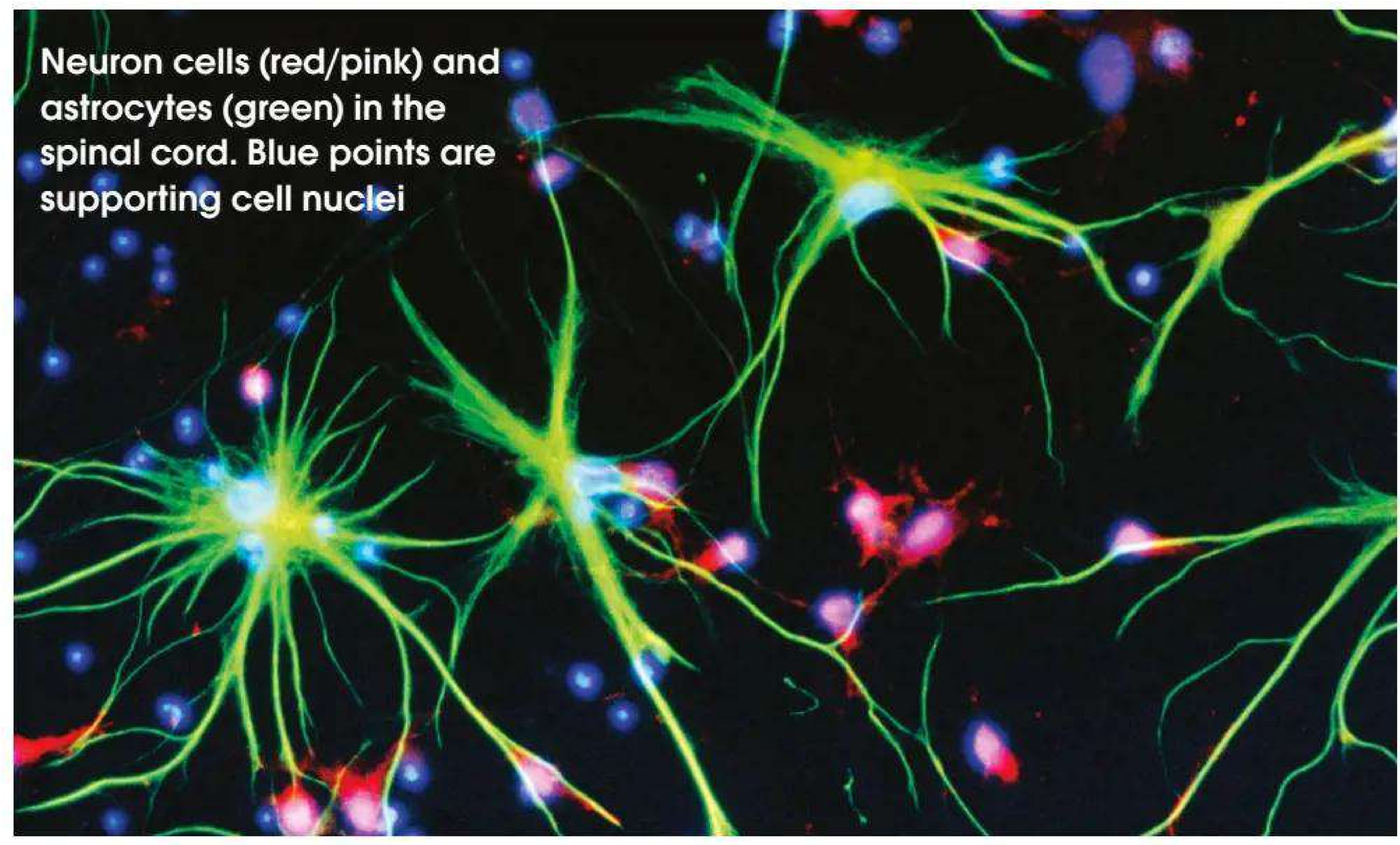
Humans have a second type of fat tissue known as 'brown fat'. More commonly found in infants, brown fat provides a thermal blanket around the neck and the major blood vessels in the thorax. Brown fat cells are able to generate heat by a method known as uncoupling; instead of using glucose to make energy for the cell in the form of ATP, the brown fat can release the energy as heat. This is thought to be very important in newborns, who lack the ability to keep warm by shivering.



Getting on your nerves
The cerebral cortex of a male human brain contains around 23 billion neurons



A scan of a normal brain (right) and another with Alzheimer's (left)



Neuron cells (red/pink) and astrocytes (green) in the spinal cord. Blue points are supporting cell nuclei

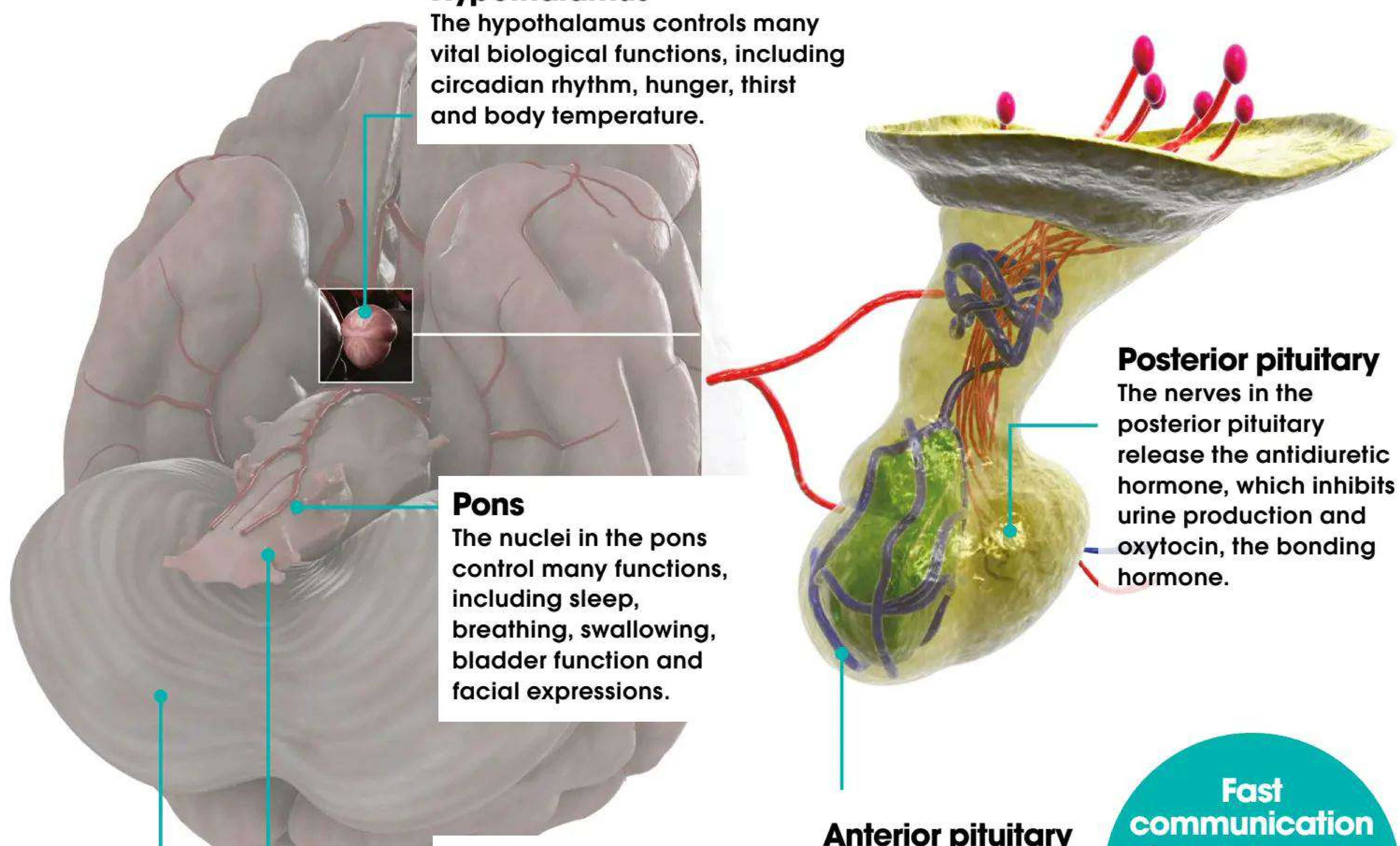
Inside the brain

The brain is made up of two major types of cells: neurons and glial cells. The neurons of the brain are highly specialised cells, interconnected by long, branching processes. They communicate through electrical 'action potentials', which can travel along the axons at speeds of one to 100 metres (3.3-328 feet) per second.

When an action potential reaches the synapse at the end of a nerve, it triggers the release of chemical transmitters, which bind to receptors on neighbouring nerves. Depending on the combination of neurotransmitters released – and the timing – the target nerve will fire, propagating the signal through the brain.

Glial cells, on the other hand, provide support to the neurons and have a variety of specialist functions. Astrocytes help to take up excess neurotransmitters from synapses, preventing neurons from damage due to excessive stimulation, while oligodendrocytes form fatty sheaths in order to insulate nerve cells in the brain and spinal cord.

The brain has significantly more protection than the other organs of the body. It is shielded from mechanical stress by the thick bones of the skull and is suspended in a cushion of cerebrospinal fluid. At the microscopic level, the brain is protected from potential hazards in the bloodstream by the blood-brain barrier – the cells lining the capillaries are joined together by tight junctions, controlling the passage of all molecules and bacteria into the organ.



Hypothalamus
The hypothalamus controls many vital biological functions, including circadian rhythm, hunger, thirst and body temperature.

Pons
The nuclei in the pons control many functions, including sleep, breathing, swallowing, bladder function and facial expressions.

Posterior pituitary
The nerves in the posterior pituitary release the antidiuretic hormone, which inhibits urine production and oxytocin, the bonding hormone.

Cerebellum
The cerebellum has an important role in the co-ordination and timing of movement.

Medulla oblongata
The lower half of the brainstem is responsible for controlling fundamental involuntary functions like breathing and heartbeat.

Anterior pituitary
The anterior pituitary generates several different hormones, controlling growth, thyroid function, fertility and stress.

Fast communication
The fastest nerves in the body can transmit electrical signals at 120m (394ft) per second

The ageing body

We may not be able to stop it, but we can begin to understand it

The human body changes as it ages, and the peak time for organ functionality is thought to be around the age of 30. The body has amazing capacity for regeneration, but cells can only divide a finite number of times, and as we get older our ability to repair damaged tissue decreases.

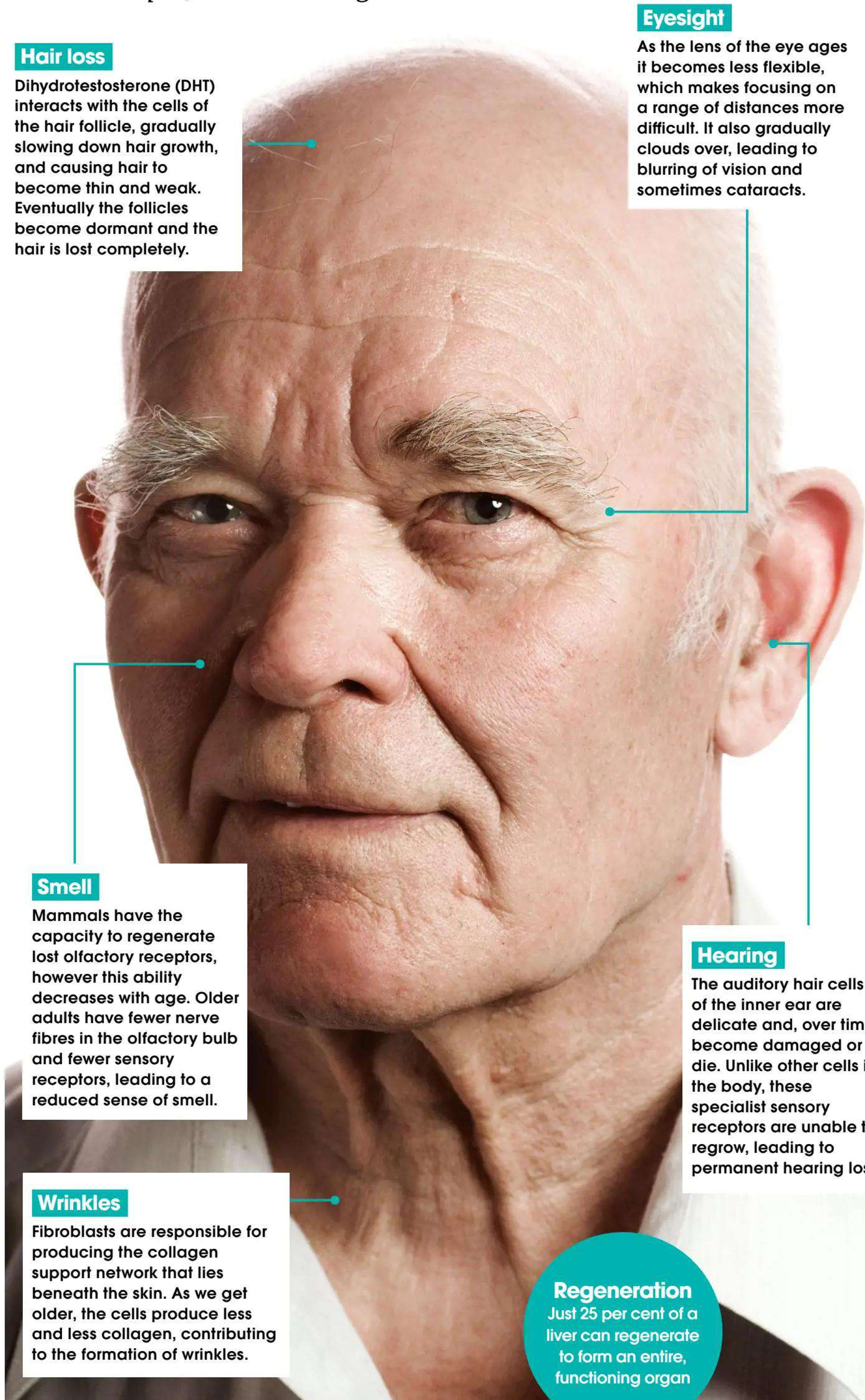
Dramatic changes, such as the menopause, produce obvious effects on the body. Female sex hormones are not just involved in reproduction, but also play a role in other processes, such as the maintenance of bone density. In the absence of oestrogen, bone mineral density decreases, which can lead to osteoporosis. A similar, but less dramatic, effect can be seen in men as testosterone levels begin to drop.

Similar decline in functionality can be observed throughout the human body; collagen in the skin begins to decrease, insulated axons in the brain shorten, and DNA damage accumulates, leading to an ever greater risk of cancer.

However, it's not all bad. Life expectancy is on the increase, and scientists are coming closer to understanding – and being able to slow – the complex processes of human ageing.

As the body gets older it becomes more susceptible to faulty cells that cause cancer

Arthritis is the main cause of disability in over-55s in industrialised countries



Hair loss
Dihydrotestosterone (DHT) interacts with the cells of the hair follicle, gradually slowing down hair growth, and causing hair to become thin and weak. Eventually the follicles become dormant and the hair is lost completely.

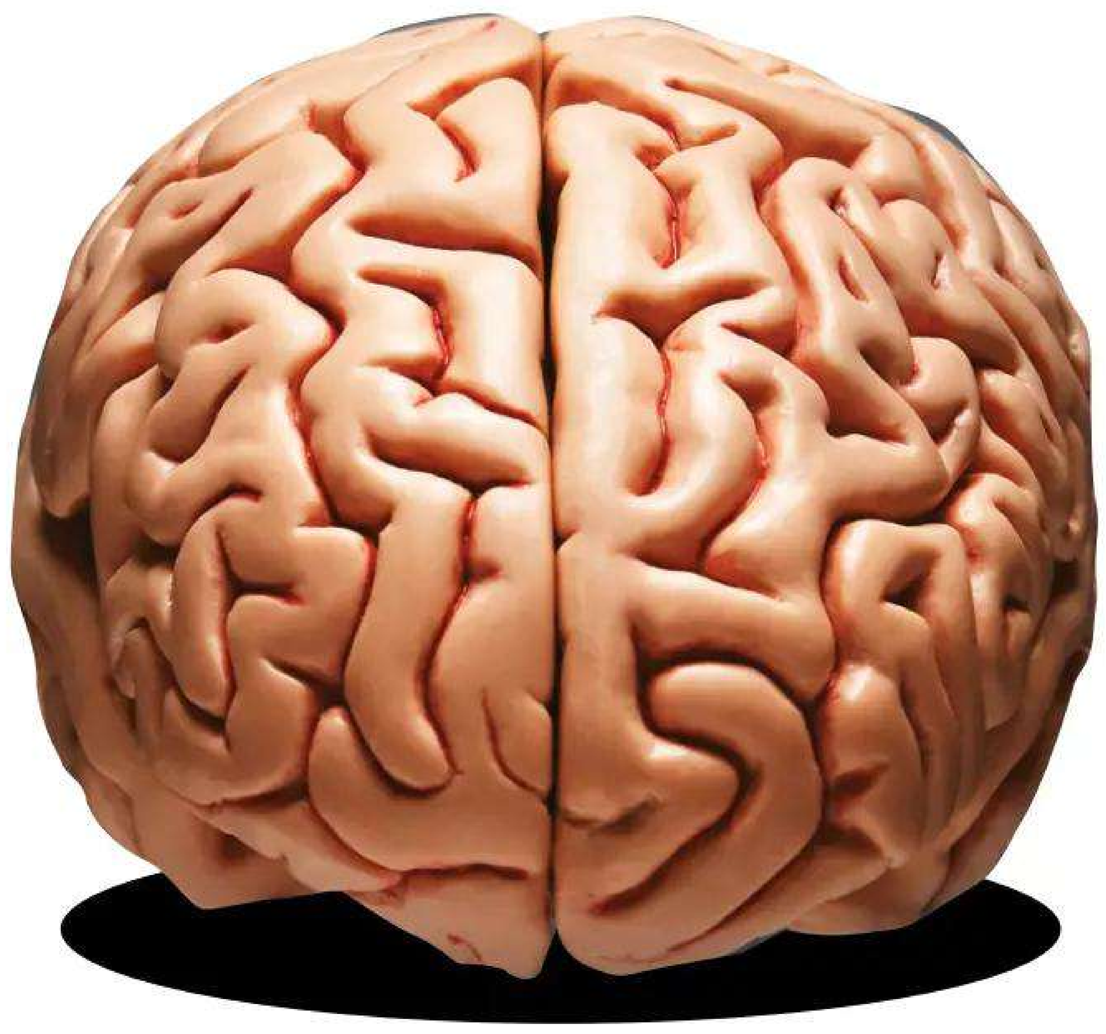
Eyesight
As the lens of the eye ages it becomes less flexible, which makes focusing on a range of distances more difficult. It also gradually clouds over, leading to blurring of vision and sometimes cataracts.

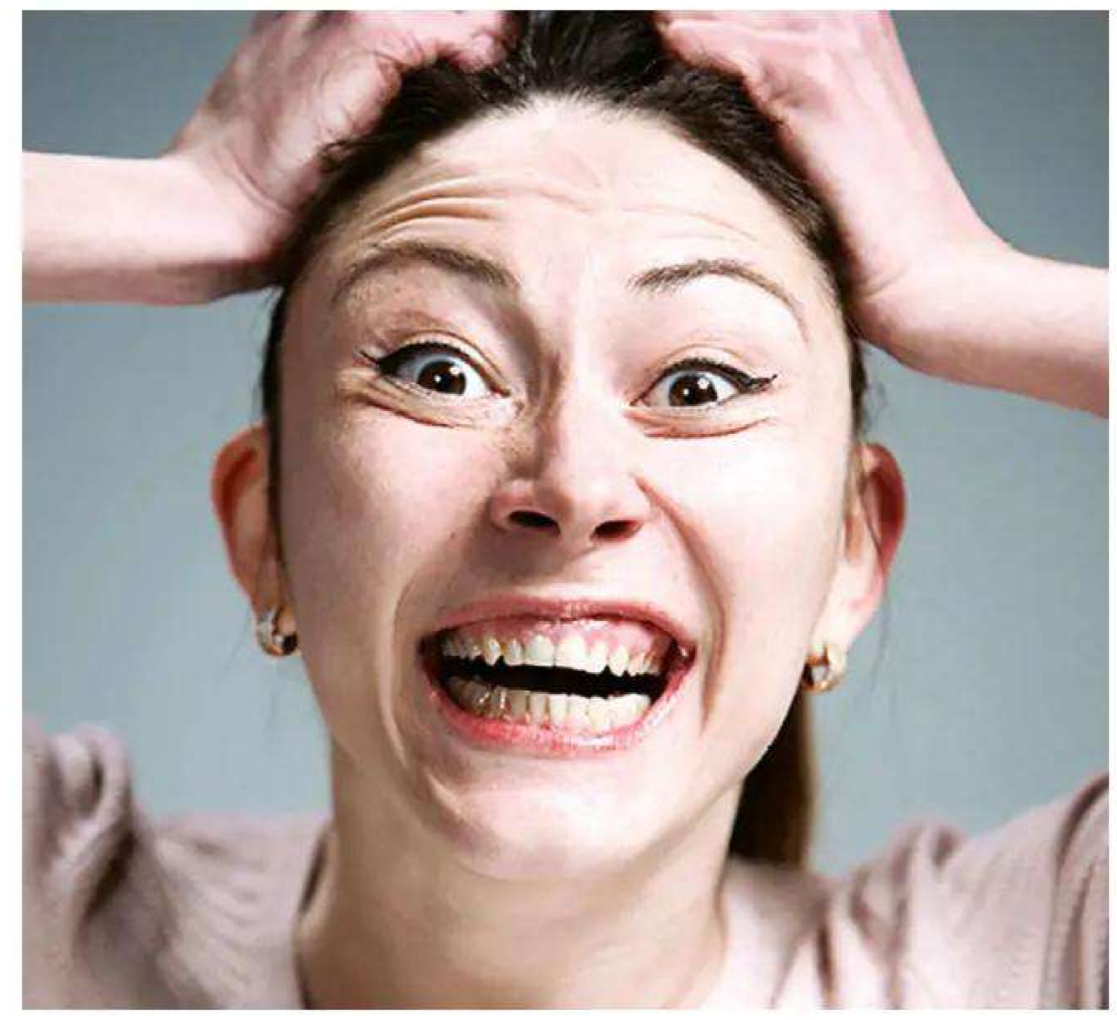
Smell
Mammals have the capacity to regenerate lost olfactory receptors, however this ability decreases with age. Older adults have fewer nerve fibres in the olfactory bulb and fewer sensory receptors, leading to a reduced sense of smell.

Hearing
The auditory hair cells of the inner ear are delicate and, over time, become damaged or die. Unlike other cells in the body, these specialist sensory receptors are unable to regrow, leading to permanent hearing loss.

Wrinkles
Fibroblasts are responsible for producing the collagen support network that lies beneath the skin. As we get older, the cells produce less and less collagen, contributing to the formation of wrinkles.

Regeneration
Just 25 per cent of a liver can regenerate to form an entire, functioning organ





Science of emotions

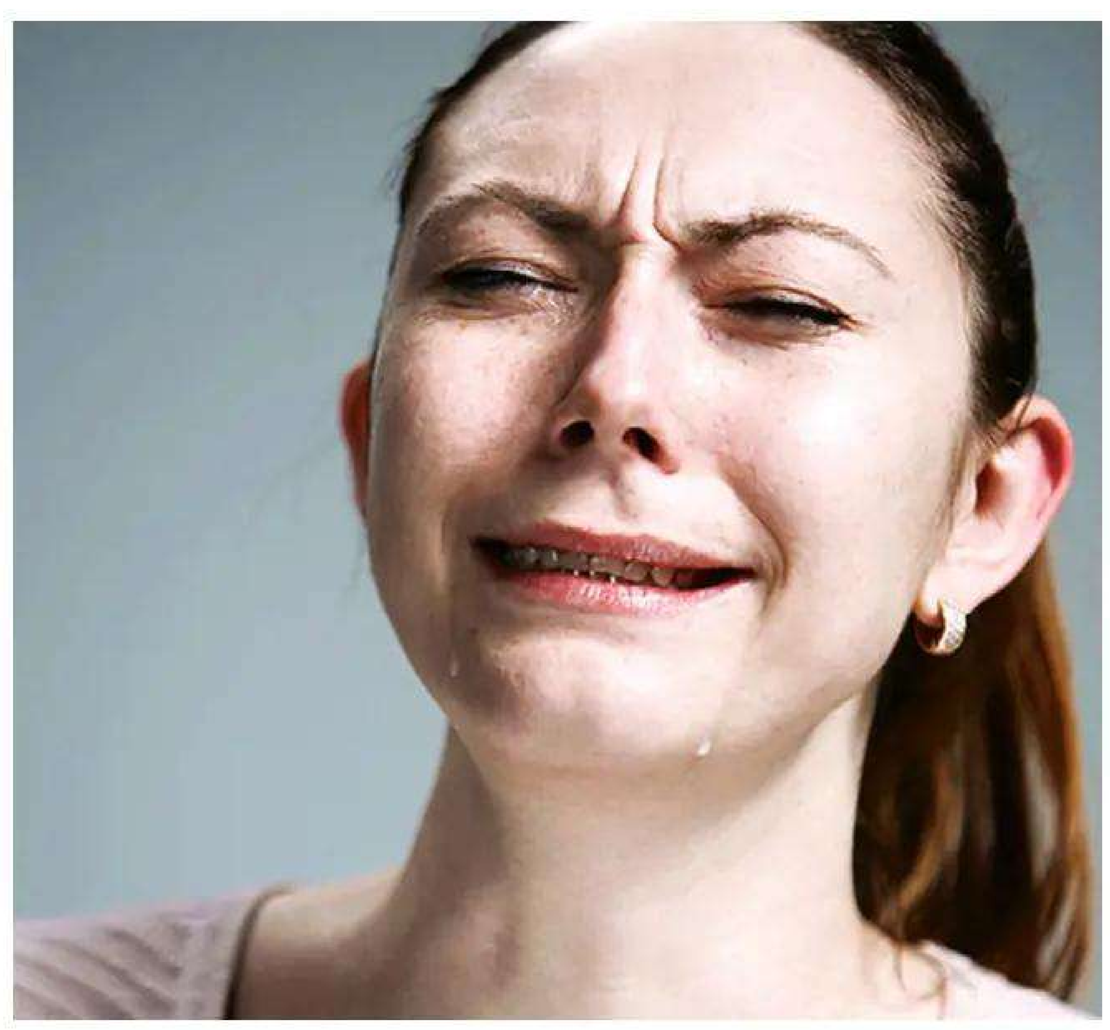
How our ancient brains evolved the perfect way to keep us safe by controlling the chemicals in our minds to moderate our behaviour

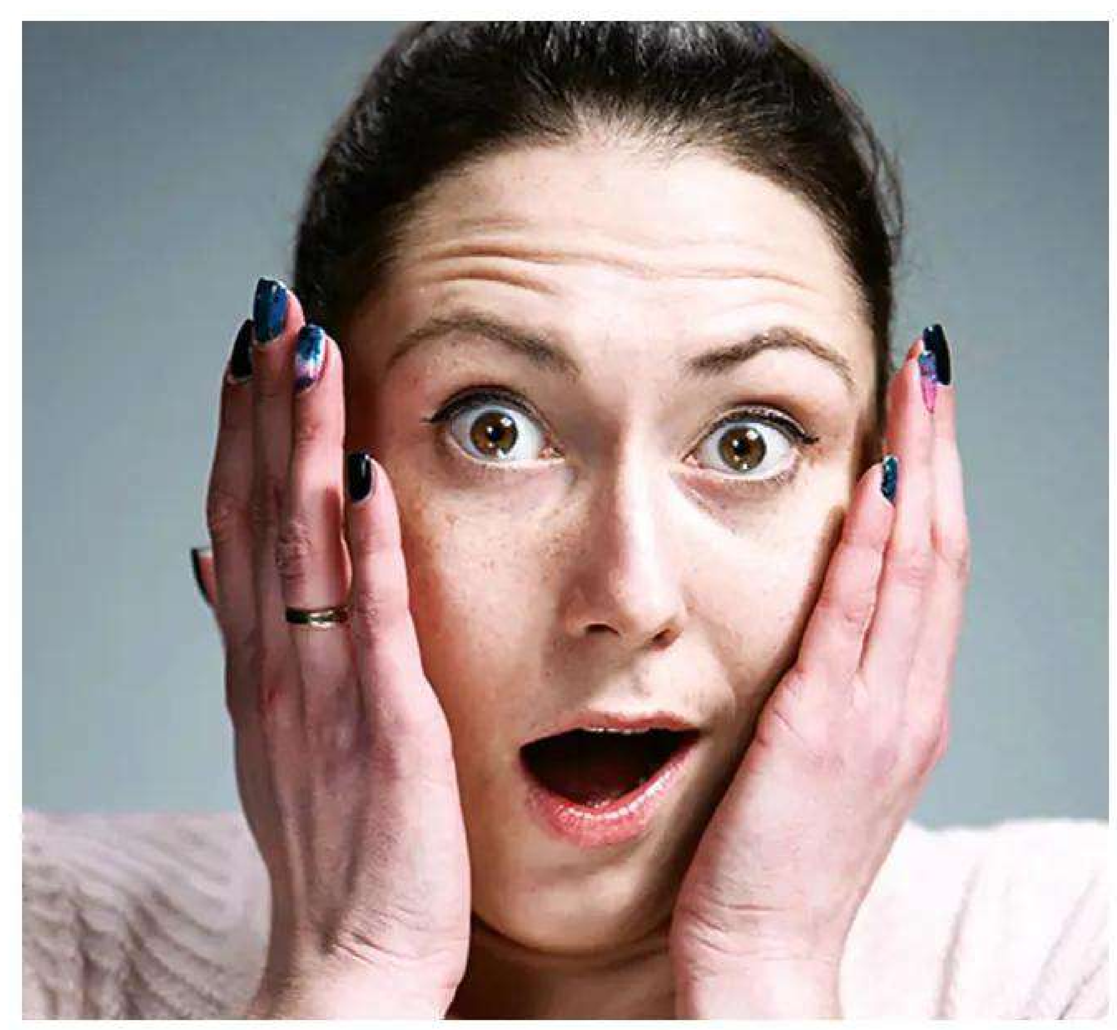
How are you feeling right now? Are you relaxed laying on your sofa and listening to the gentle sounds of the dawn chorus outside your window? Or maybe you are tense with your shoulders hunched up around yourself as you try to get five minutes peace in a busy office? You would think that it is easy to work out if we are happy or sad, angry or calm, but humans cycle through such a vast array of emotions throughout their lives it can be difficult to distinguish them from one another.

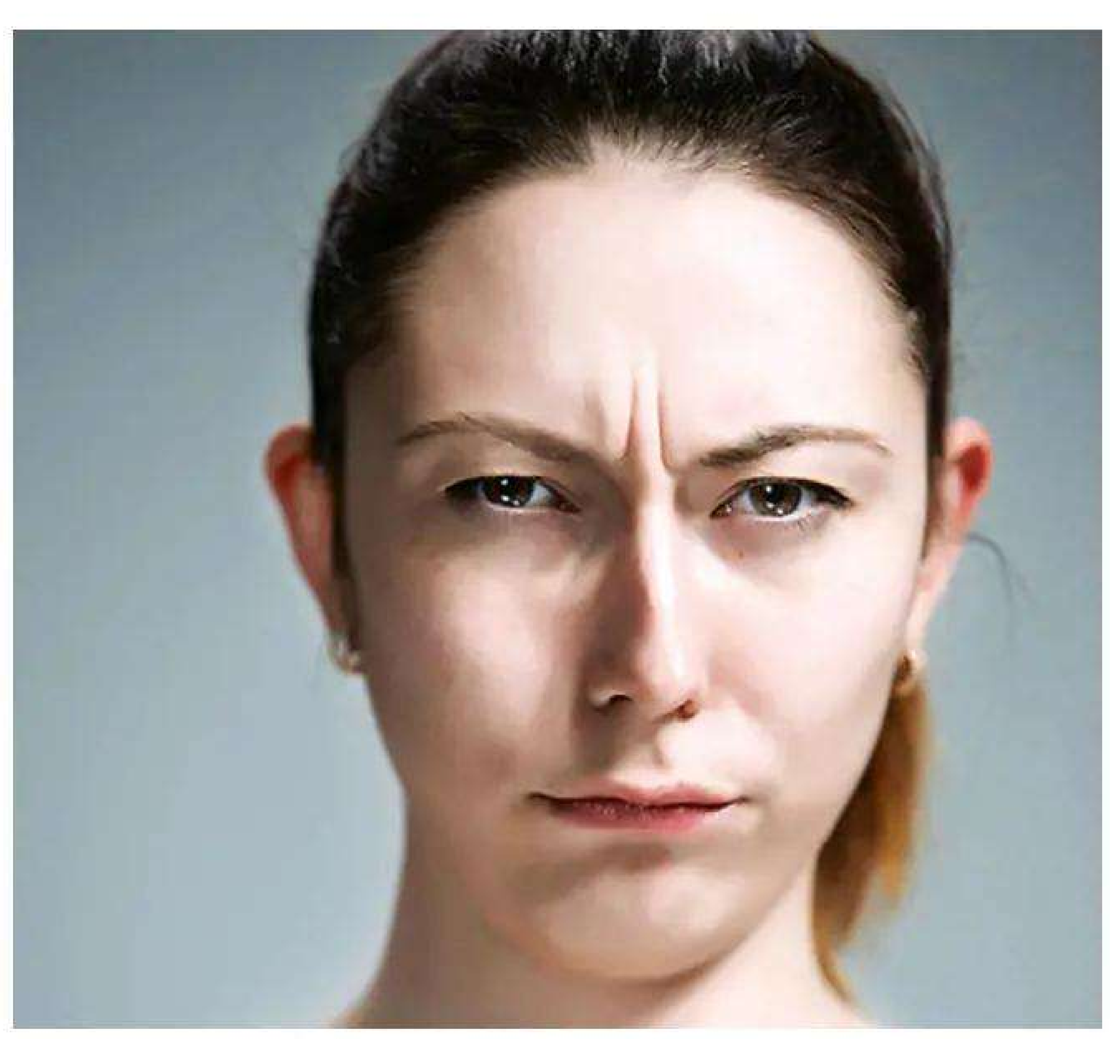
Emotions are not a simple experience. Every time you feel something, your body initiates a physiological change, a chemical release and a behavioural response. This process involves multiple processes working together, including your major organs, neurotransmitters and limbic system.

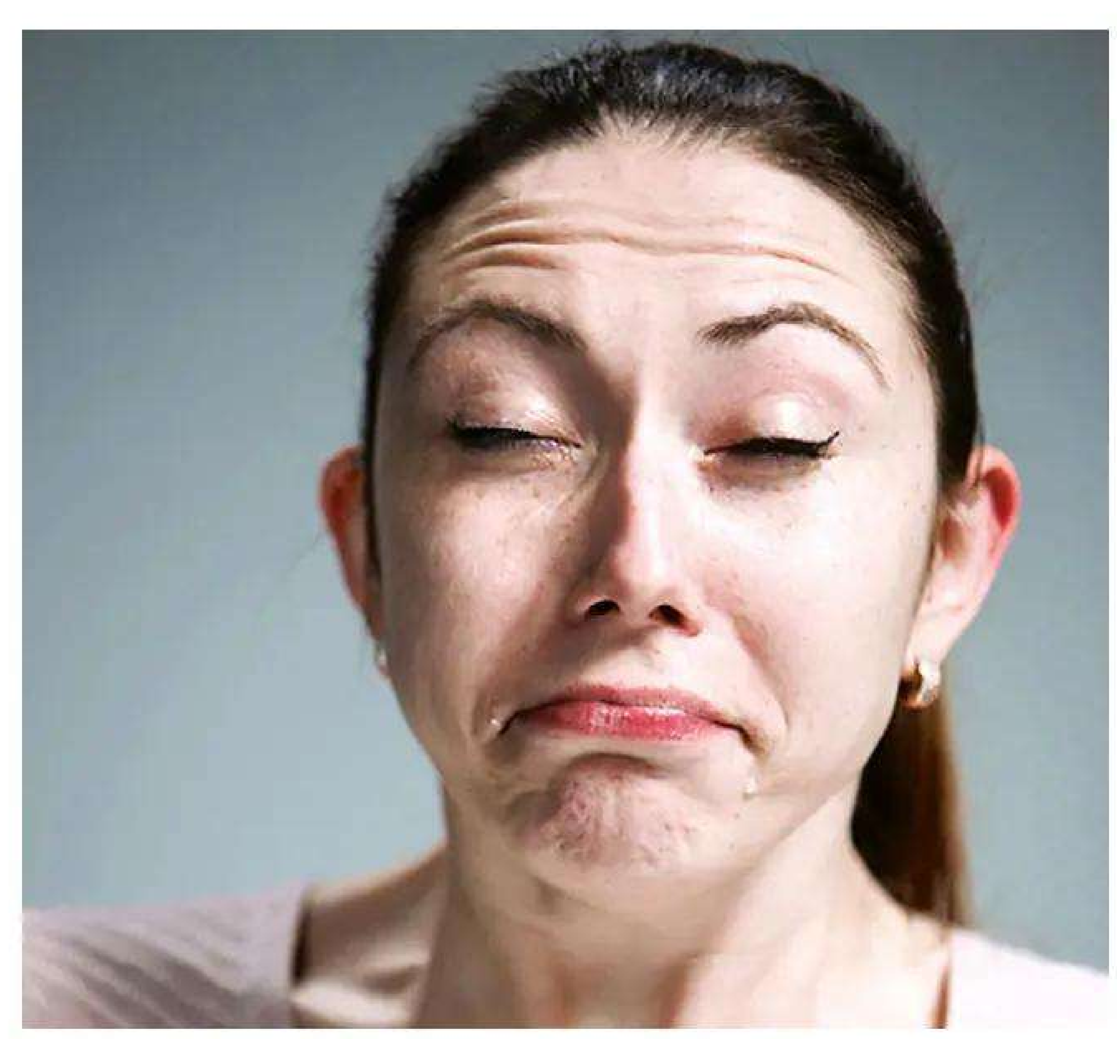
Your limbic system is the most primordial part of your brain, thought to have first evolved in early mammals. It's filled with ancient neural pathways that activate our emotions in response to stimuli and controls our fight-or-flight response through the autonomic nervous system.

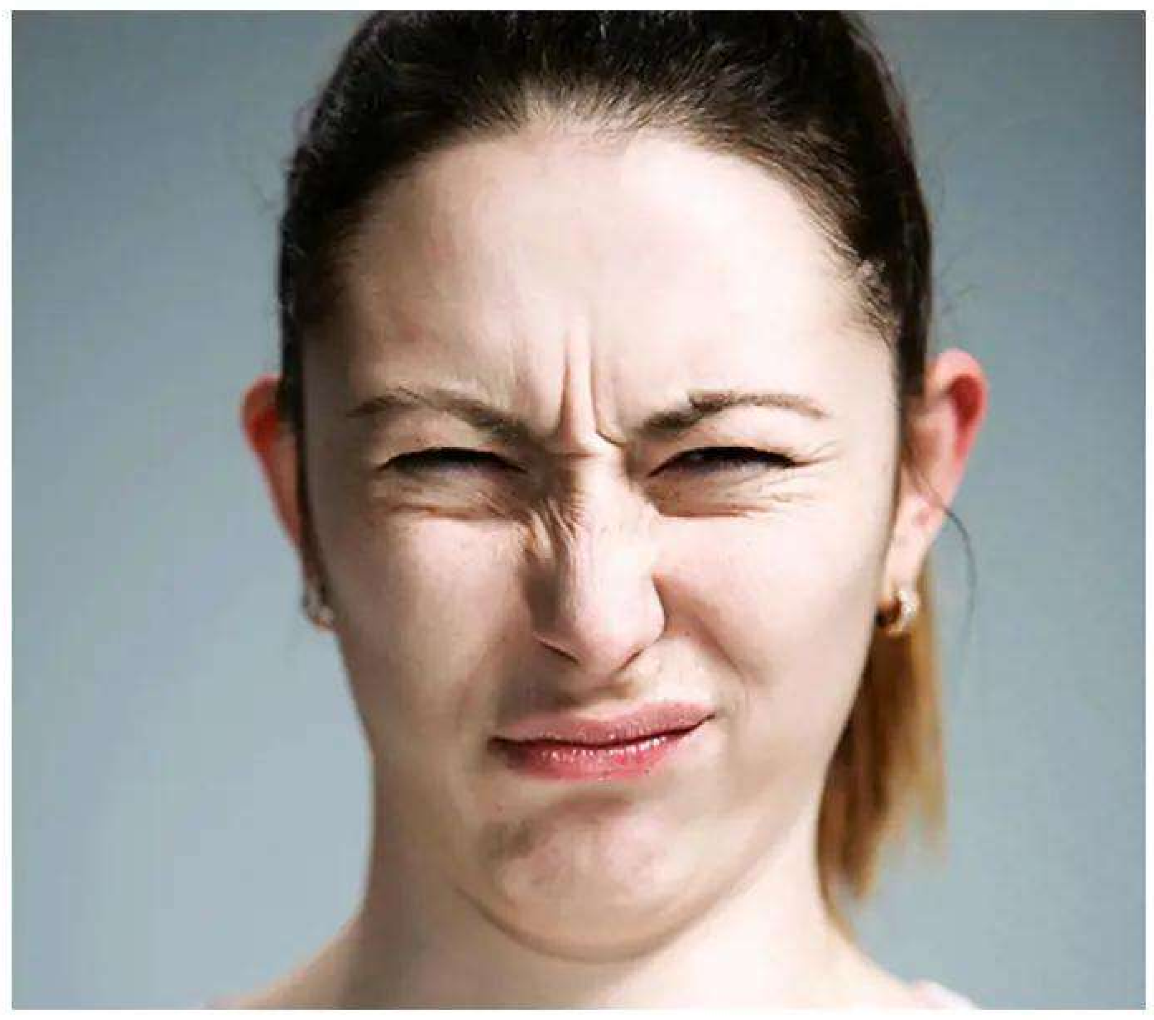
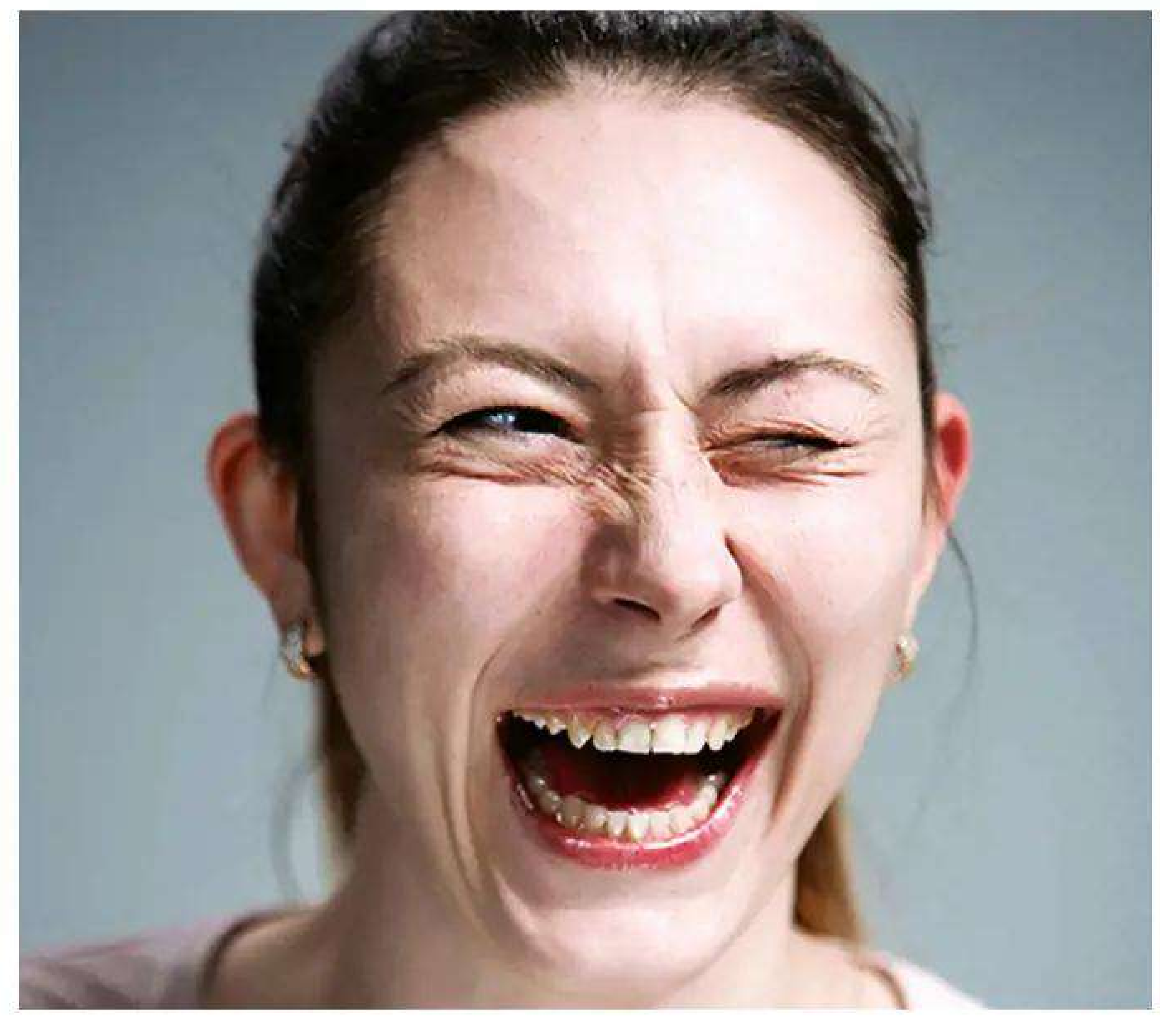
This response evolved from a need to make decisions based on our emotions. As our body fills with adrenaline and our heart starts racing, we

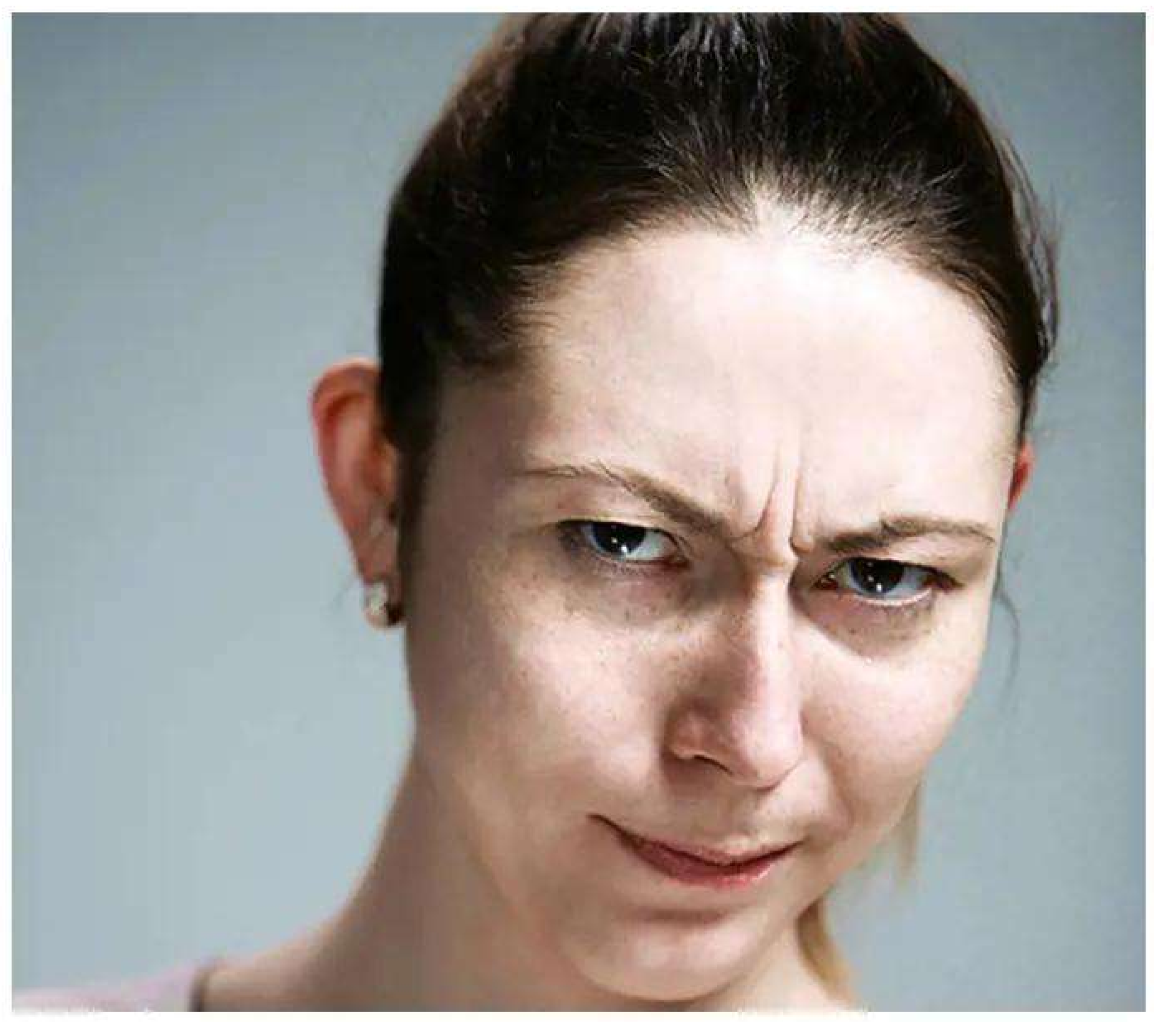


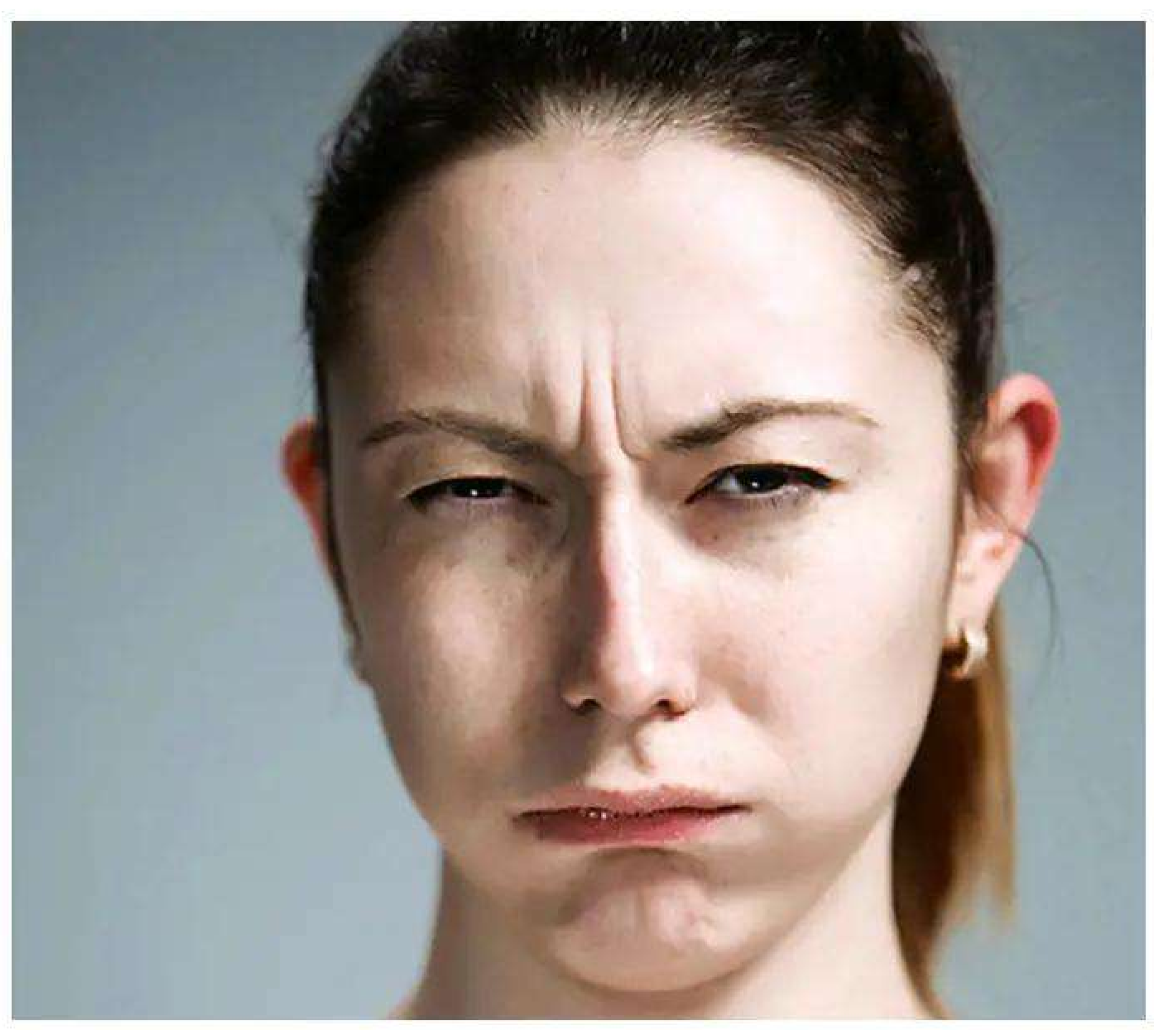
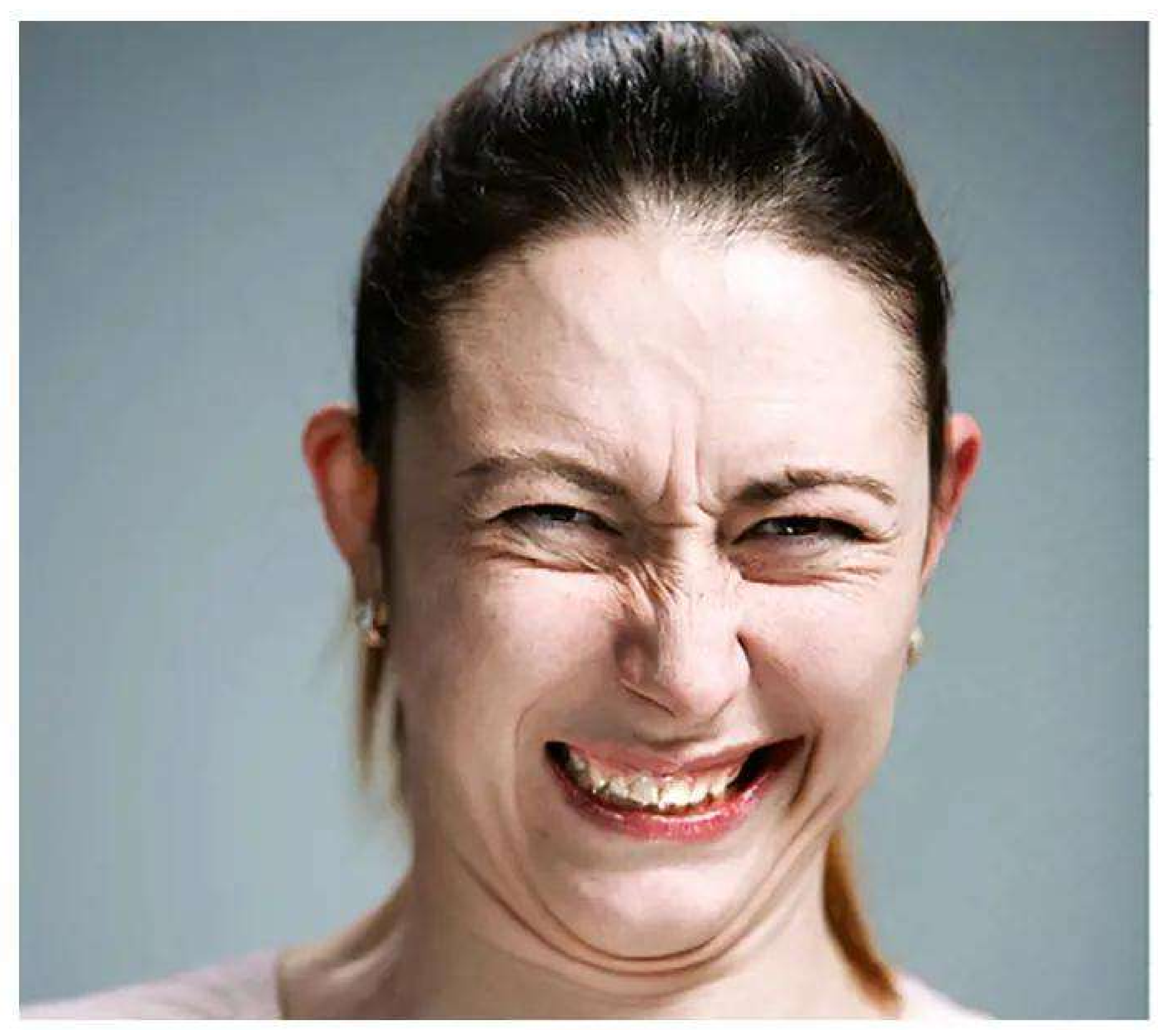









prepare to react. Do we stay to fight the bear that has come scavenging for food, or do we flee to somewhere safe? We can still feel the effects of this response. When we are confronted for not doing the dishes, we might feel the same fight-or-flight response as our adrenaline starts to flood our system. Our heart rate and breathing increases, the fine hairs on our arms might stand on end, and our hands feel clammy as we decide if we are going to stay and argue or if we are going to escape to the safety of our bedroom.

The biological sensations in our bodies in response to emotions can feel very similar to one another. Imagine your palms sweating, feeling your cheeks warm as they flush red, and your

"We feel our emotions, and not just in our head and heart – our bodily state changes to react to the chemical storm in our system"

heart pounding in your chest. You could feel this because you are sitting nervously in the dentist's waiting room, or you could be excited as you wait to see your loved ones after they return from a holiday – the physiological reaction is the same. The interpretation of emotions is our logical brain rationalising these responses and describing them as feelings. We take into consideration the context and label our emotions accordingly. However, we don't all do this the same way. Because our bodies cause different floods of chemicals in response to different environmental triggers, each person naturally reacts to situations differently.

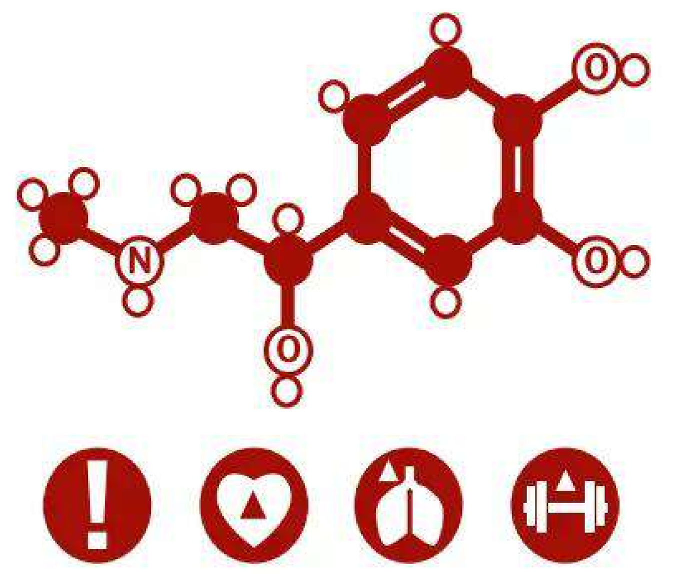
Have you ever seen someone who is being berated in a meeting but facing the onslaught with nothing more than a slightly raised eyebrow? Or watched as someone finds out some bad news but keeps their composure? You are sure that you would have raised your voice or burst into tears, but our responses are defined by how our neurons are networked together. Our past experiences and genetic predispositions influence our brain chemistry and therefore our physiological responses, which in turn determine how we react to various situations – like someone cancelling on us last minute, or having a friend surprise us by showing up at the front door unannounced.

At times our emotions can seem like an irrational response, but our brains have carefully evolved these mechanisms with just one target – keeping us alive. While we interpret different

The chemistry of emotions

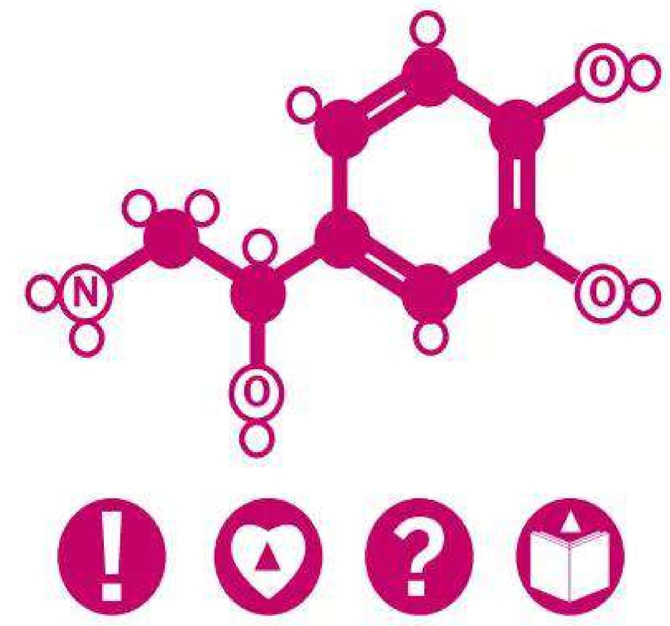
Where two neurons meet, a very small gap (synapse) exists between them. The electrical impulse travelling along the axon of the neuron must convert into a chemical signal to bridge this gap.

The chemicals that do this are called neurotransmitters. These so-called chemical messengers are involved in our different responses to situations. Your emotions depend on fluctuating levels of neurotransmitters, which cause the activation of different parts of the brain responsible for different moods, or activate parts of the brain that trigger the stimulation of the autonomic nervous system.



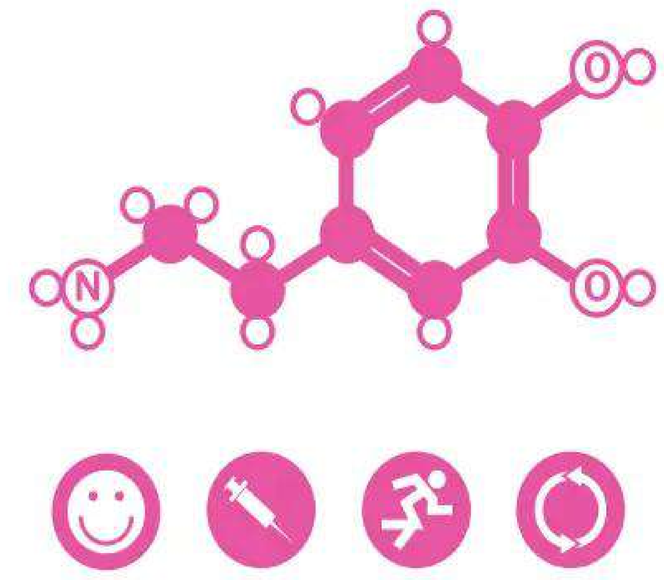
Adrenaline

Released by the adrenal glands that sit on top of each kidney, adrenaline increases the flow of blood to our muscles, raises our heart rate and dilates our pupils. It is crucial in our fight-or-flight survival response.



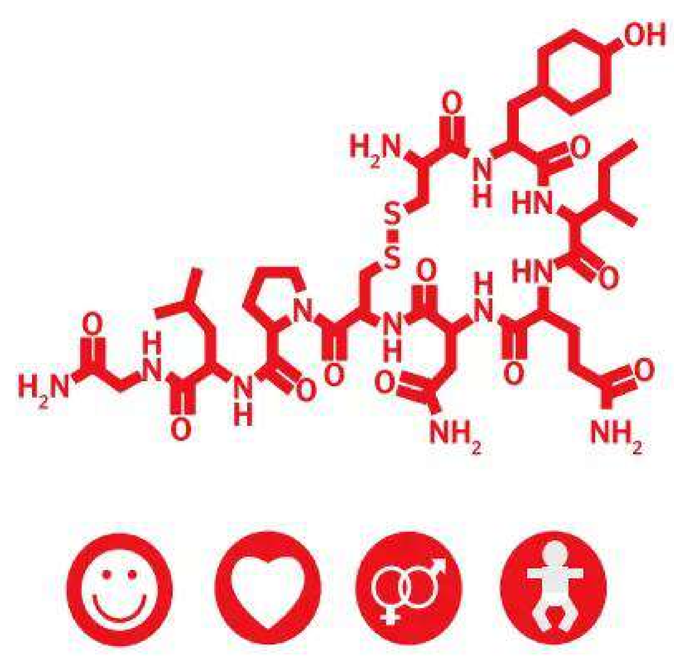
Noradrenaline

Similar to adrenaline, the release of this chemical can result in increased levels of alertness, helping to prime us for action if needed. It also increases our blood pressure and widens our air passages.



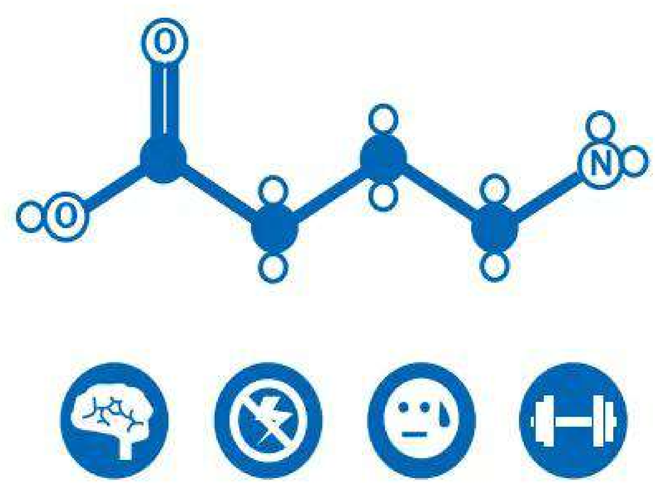
Dopamine

This is the addictive reward chemical that your brain craves. It serves to motivate you to seek out the things you need for your survival. We can sometimes find ourselves enslaved by this ancient reward mechanism.



Oxytocin

Also known as the 'cuddle hormone', oxytocin is released when you're close to another person. It's essential for making strong social bonds, and it's also a key part of why we want to trust people.

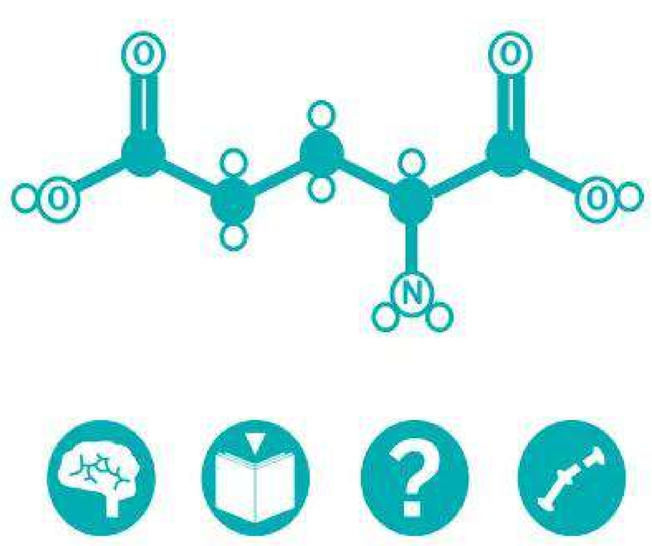


GABA

Responsible for regulating muscle tone, gamma-Aminobutyric acid (GABA) also regulates the communication between brain cells. It can calm us down by reducing the rate at which our neurons fire.

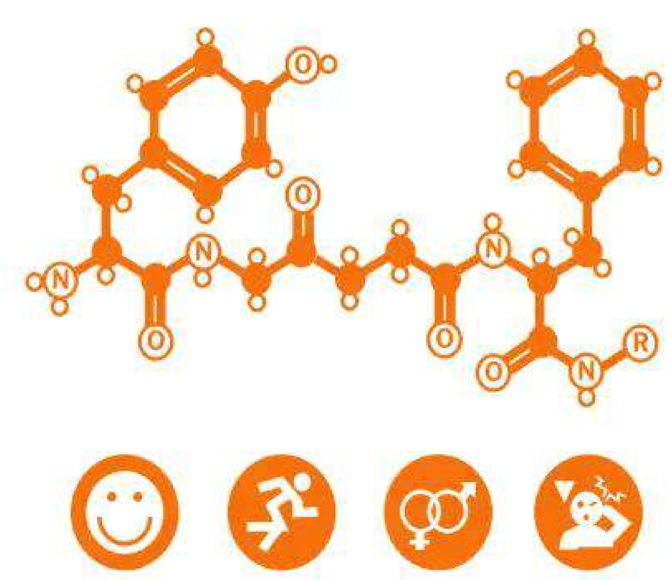
Acetylcholine

This is the main neurotransmitter in the parasympathetic nervous system that slows our heart rate, contracts smooth muscles, dilates blood vessels and increases bodily secretions.



Glutamate

The most abundant neurotransmitter in the vertebrate nervous system, glutamate is used by nerve cells to transmit signals to other cells. Too much of it can cause cognitive impairments.



Endorphins

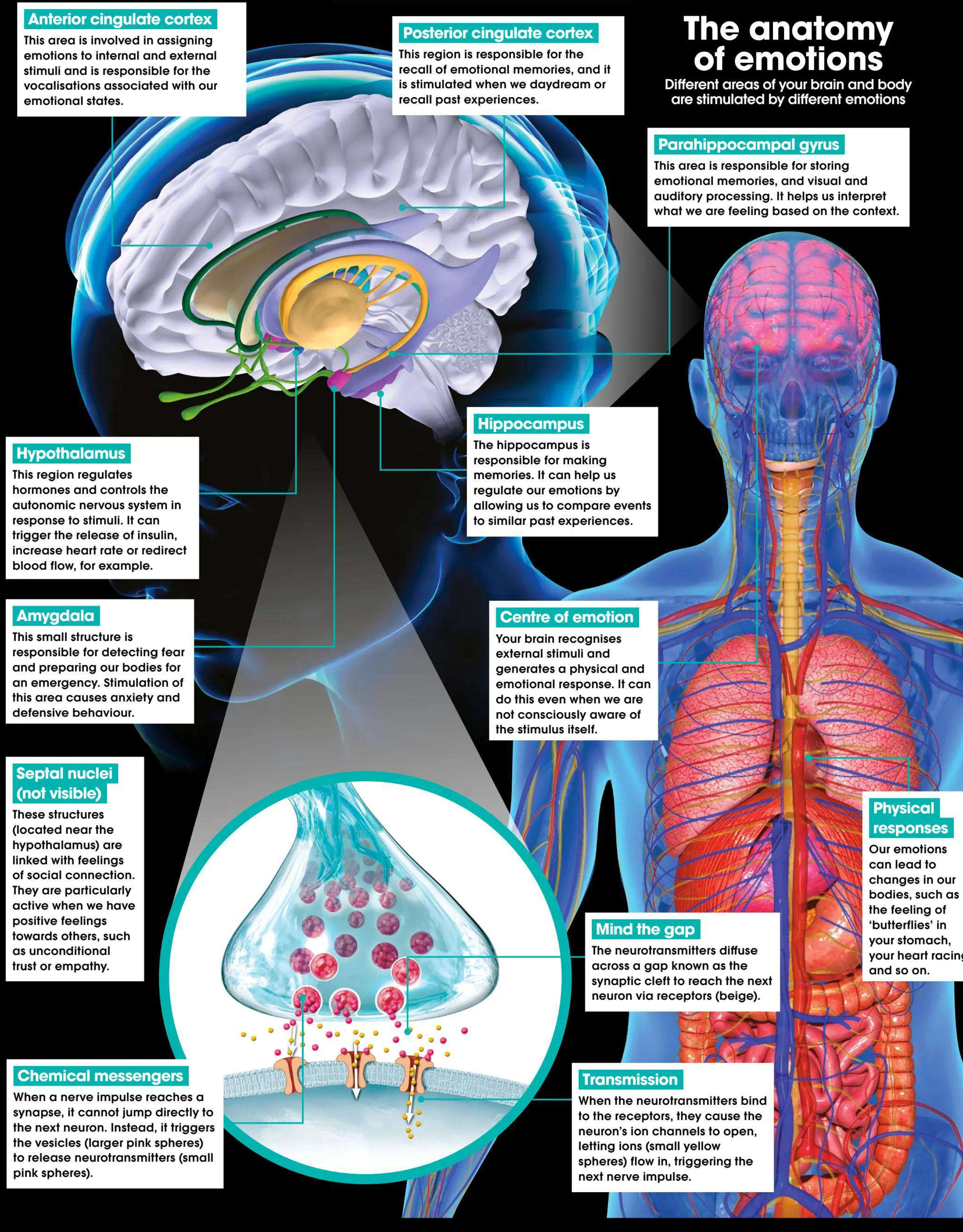
Triggered by the sensation of pain, endorphins work to inhibit the transmission of pain signals. Capable of producing a sense of euphoria, studies have suggested endorphins may also be stimulated by laughter.

Serotonin

Serotonin is linked to our wellbeing and happiness, and our levels of it are affected by exercise and exposure to sunlight. It also helps to regulate our mood balance, sleep cycle and digestion.

The anatomy of emotions

Different areas of your brain and body are stimulated by different emotions



Anterior cingulate cortex
This area is involved in assigning emotions to internal and external stimuli and is responsible for the vocalisations associated with our emotional states.

Posterior cingulate cortex
This region is responsible for the recall of emotional memories, and it is stimulated when we daydream or recall past experiences.

Parahippocampal gyrus
This area is responsible for storing emotional memories, and visual and auditory processing. It helps us interpret what we are feeling based on the context.

Hippocampus
The hippocampus is responsible for making memories. It can help us regulate our emotions by allowing us to compare events to similar past experiences.

Hypothalamus
This region regulates hormones and controls the autonomic nervous system in response to stimuli. It can trigger the release of insulin, increase heart rate or redirect blood flow, for example.

Amygdala
This small structure is responsible for detecting fear and preparing our bodies for an emergency. Stimulation of this area causes anxiety and defensive behaviour.

Centre of emotion
Your brain recognises external stimuli and generates a physical and emotional response. It can do this even when we are not consciously aware of the stimulus itself.

Septal nuclei (not visible)
These structures (located near the hypothalamus) are linked with feelings of social connection. They are particularly active when we have positive feelings towards others, such as unconditional trust or empathy.

Physical responses
Our emotions can lead to changes in our bodies, such as the feeling of 'butterflies' in your stomach, your heart racing, and so on.

Mind the gap
The neurotransmitters diffuse across a gap known as the synaptic cleft to reach the next neuron via receptors (beige).

Chemical messengers
When a nerve impulse reaches a synapse, it cannot jump directly to the next neuron. Instead, it triggers the vesicles (larger pink spheres) to release neurotransmitters (small pink spheres).

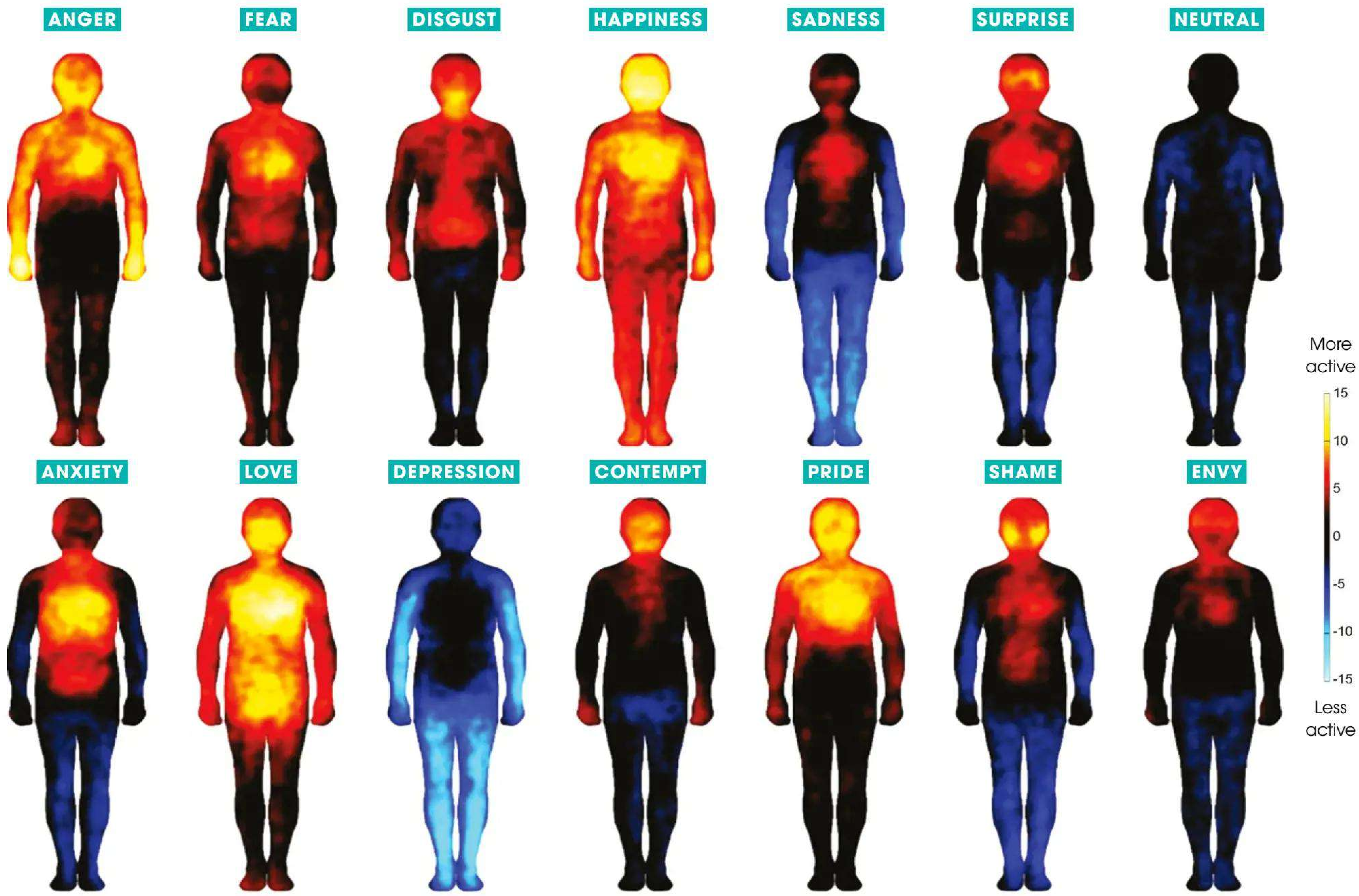
Transmission
When the neurotransmitters bind to the receptors, they cause the neuron's ion channels to open, letting ions (small yellow spheres) flow in, triggering the next nerve impulse.

The chemicals released when we're close to our family help us to build trust and closeness

emotions as positive or negative, the most ancient parts of the human brain developed them on the principle that we must survive. We evolved emotions as a means of communicative function and to help us navigate social interactions and our environment safely: they are designed to protect us. Our fear responses were originally a survival tactic that warned us of potential dangers, such as our innate unease around spiders and snakes. Then there is the feeling of disgust, which warns us of foods or other substances that may be dangerous.

Our other emotions are responses to social interactions that keep us part of a group. We are fundamentally a social species, and throughout our evolution have relied on our tribe to help us survive by working together to find food and shelter. Anger is a response to perceived social threats or a signal of dominance, pride can help us to boost our social status, while shame is intended to decrease our standing within a group. These emotions maintain the social balance of our tribe – who we follow, who we trust, who we care about.

The fundamental emotions that motivate us individually are almost always sadness and happiness. Sadness results from loss and serves the biological purpose of motivating a person to recover that loss, whether it is a young child searching for their mother in a supermarket,



Emotions as sensations

We feel our emotions, and not just in our head and heart – our bodily state changes to react to the chemical storm in our system. We might feel a tight knot in our stomach as we dread walking onto a stage to give a speech, or we might feel our cheeks flush red when we answer a question wrong.

Researchers from Aalto University in Finland explored how humans physically feel their emotions by mapping the sensations topographically. Their findings were consistent across Western European and East Asian cultures, which suggests the way people feel during an emotional experience stems from a biological source rather than a cultural interpretation. The study also highlighted that emotions adjust our bodily state to either prepare ourselves physically to fight or flee or to encourage us to seek out enjoyable social reactions.

The study included over 700 participants from Finland, Sweden and Taiwan, and researchers induced different emotional states before asking them to colour bodily areas on images of the human body to describe in which areas they felt activity increasing or decreasing throughout.

or trying hard to get a new job after being dismissed. But the ultimate human emotion is happiness, and we are all in search of it.

When you're sitting around a campfire, safe in the countryside with some close friends and good food, you feel happiness because you have found the resources that your primitive brain is seeking. Our species is drawn so much to happiness because this emotion is our brain's reward system for finding environments where we are free from threat. A healthy human brain copes with sadness when social bonds are broken, communicates with our loved ones and can recognise and regulate our emotions even when they do not feel particularly positive.

The next time you sit in an airport departure lounge, look for the emotions. Our bodies have created these experiences – the tears as we say goodbye, the smiles and laughter as we are reunited – for the purpose of keeping us alive. Our emotions and feelings are fundamentally what make us human, but it means we're in for a bit of a rollercoaster along the way.

The emotional mechanisms in our bodies evolved to keep us safe and connect us with others

How many emotions do we have?

It has long been thought that there are only six different emotions: anger, disgust, fear, happiness, sadness and surprise. It has been hypothesised that any other emotions are just a combination of these basic feelings, such as anticipation being caused by a mixture of fear and happiness. However, a recent study published in Proceedings of the National Academy of Sciences of the United States of America from researchers at UC Berkeley suggests that we may have many more emotions that are distinctively different to one another, but still related.

The study used 2,185 short videos with the intent to evoke emotions in the 853 participants. Clips included a cute baby playing with some fluffy puppies, a man holding a tarantula inside his mouth, and a happy couple getting married. Participants were asked to record how the videos made them feel and how strongly it evoked a response. The study suggests that there are 27 distinct emotions, including awe, awkwardness, calmness, confusion, disgust, nostalgia, sadness, sympathy, horror and triumph.

We may have more emotions than we are able to express in our languages

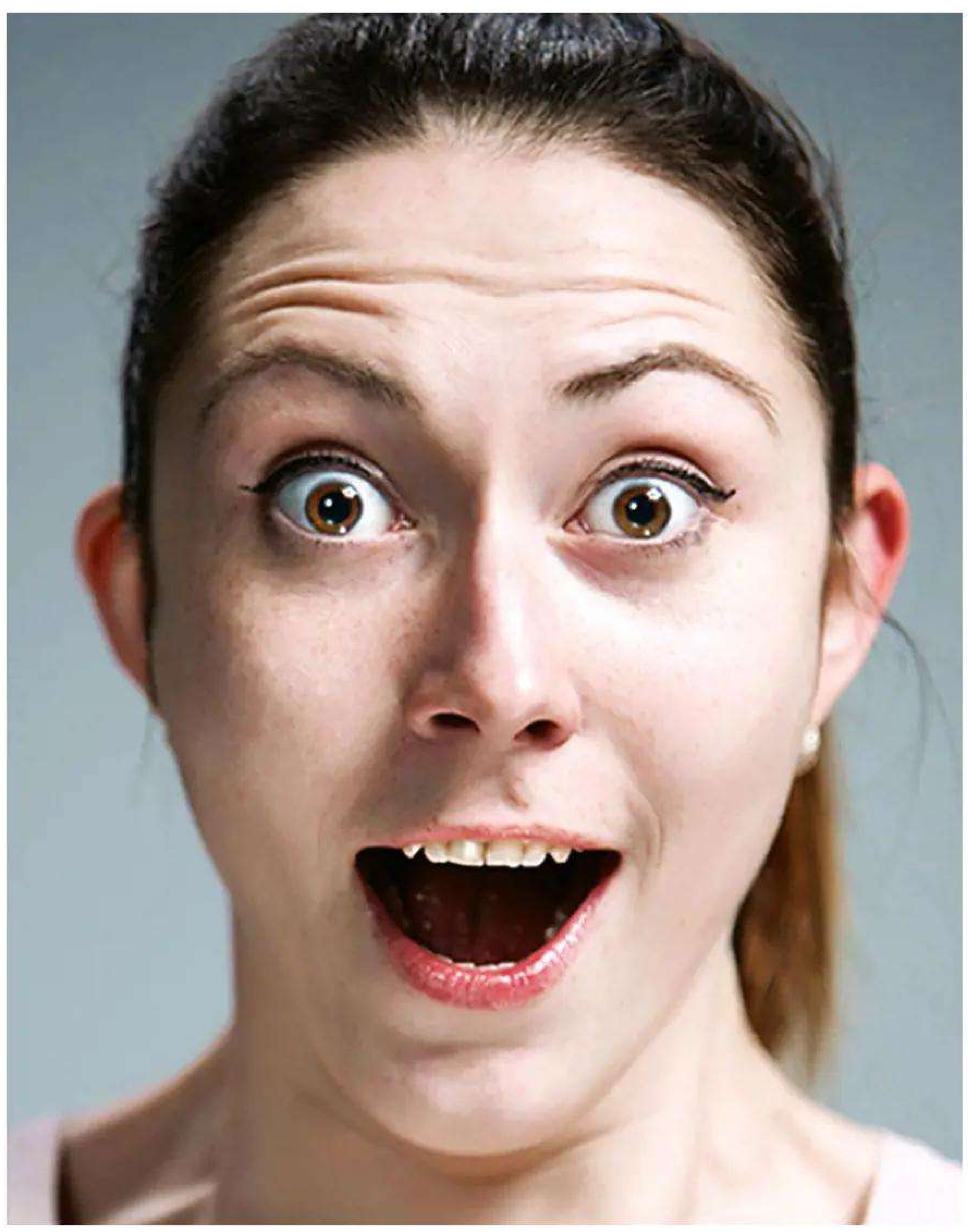
"Reading the emotions of others is a vital skill for navigating our way through life"

Universal expressions

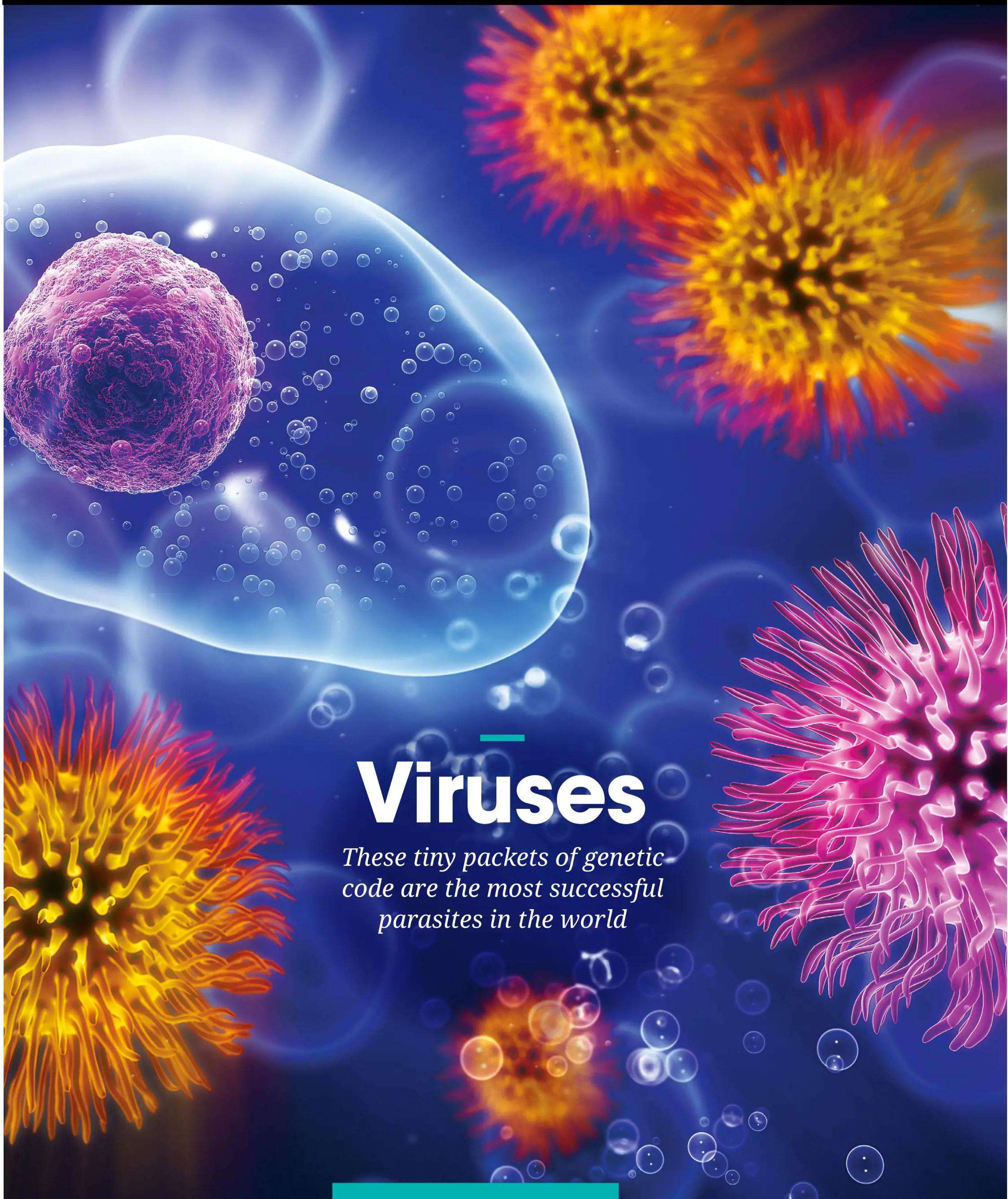
Reading the emotions of others is a vital skill for navigating our way through life – it would be awkward to misunderstand your friend as happy when they're actually angry with you.

There has been a long-established view that the way we express our feelings using our facial expressions is universal and crosses all cultures for seven basic emotions: anger, disgust, fear, joy, sadness, surprise and contempt. For over a century, studies have explored the theory of universal expression by asking people to interpret photographs displaying various emotions, although there are some cultures around the world that do not have the same perception of certain emotions.

One study found that people living in the Trobriand Islands off Papua New Guinea didn't interpret images of people who were wide-eyed with their lips parted as they gasped as a sign of fear. Instead, the Trobrianders interpreted this emotion as anger. This research is some of the first to suggest that how we express our emotions is not universal, and may differ between societies.



While the expression of happiness and sadness is generally the same all over the world, surprise and fear can be interpreted differently between cultures



Viruses

These tiny packets of genetic code are the most successful parasites in the world

Viruses are the tiniest biological replicators on the planet, roughly 100 times smaller than bacteria. Made from a small strand of genetic code and covered with a tiny protein shell, they can't 'live' on their own. In fact, scientists aren't sure whether they're even alive at all.

The cells of living organisms have their own molecular production lines. They make temporary copies of their genes and pump them through molecular machines called ribosomes. These read the genetic code and use it as a template to assemble proteins. The simplest living organisms need between 150 and 300 genes to make all the proteins they need to survive, but viruses get by on as few as four. They simply hijack other cells and turn them into virus factories.

Viruses are clever; they make up for their genetic shortfall by borrowing from the cells they infect. They don't have their own ribosomes, so they feed their code into the machines of other organisms, taking over the production line. The infected cell stops making its own proteins and starts reading virus code and assembling virus proteins.

The core of a virus is its genetic code, which is stored in the same strings of biological letters used by living organisms. Some viruses have two strands of DNA like us, others get by with just one strand, and some carry their genes as RNA. This molecule is like DNA but with a different chemical letter, and it's used by living cells to make temporary copies of genes. Some viruses also carry the code to make an enzyme

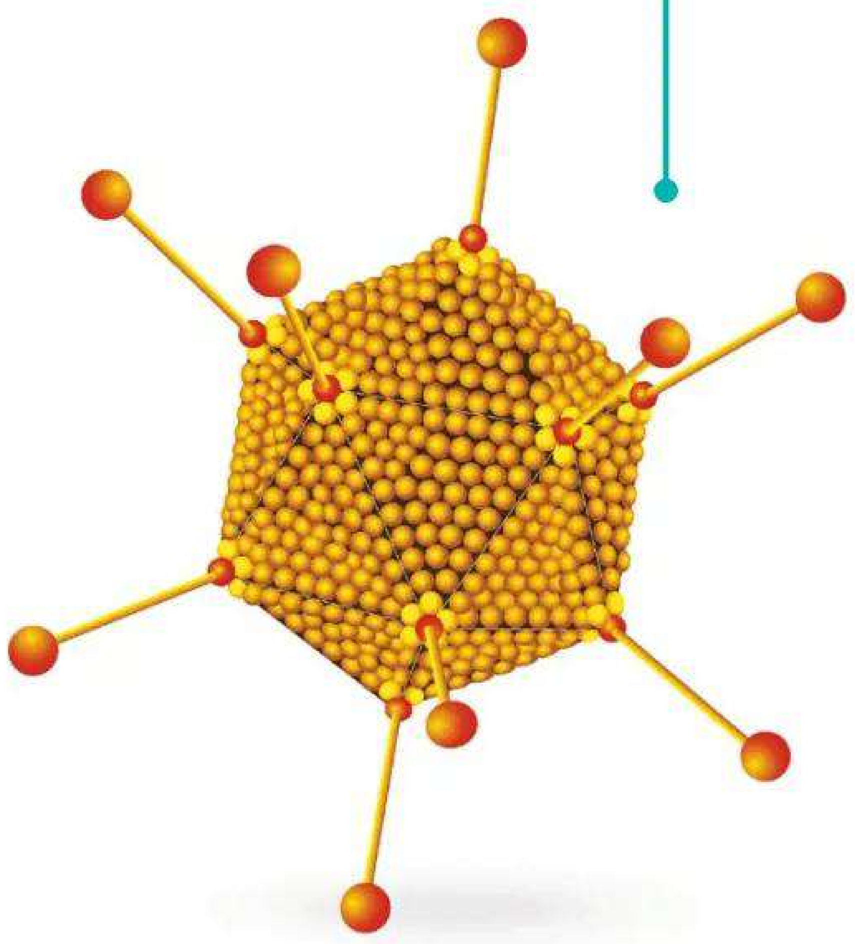
All shapes and sizes

Viruses may be small and simple, but they're very effective

Virologists use protective equipment to study human viruses in the lab

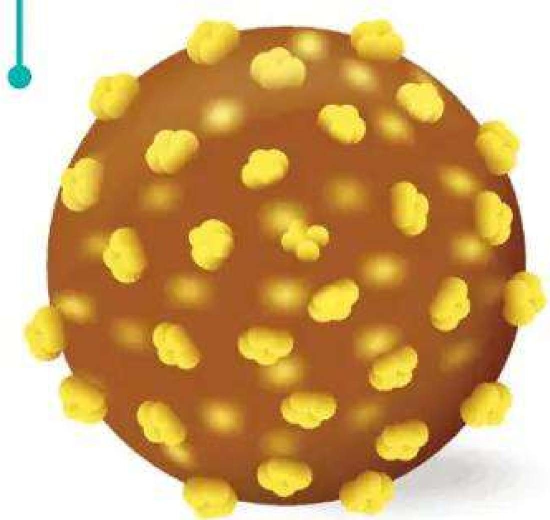
Polyhedral

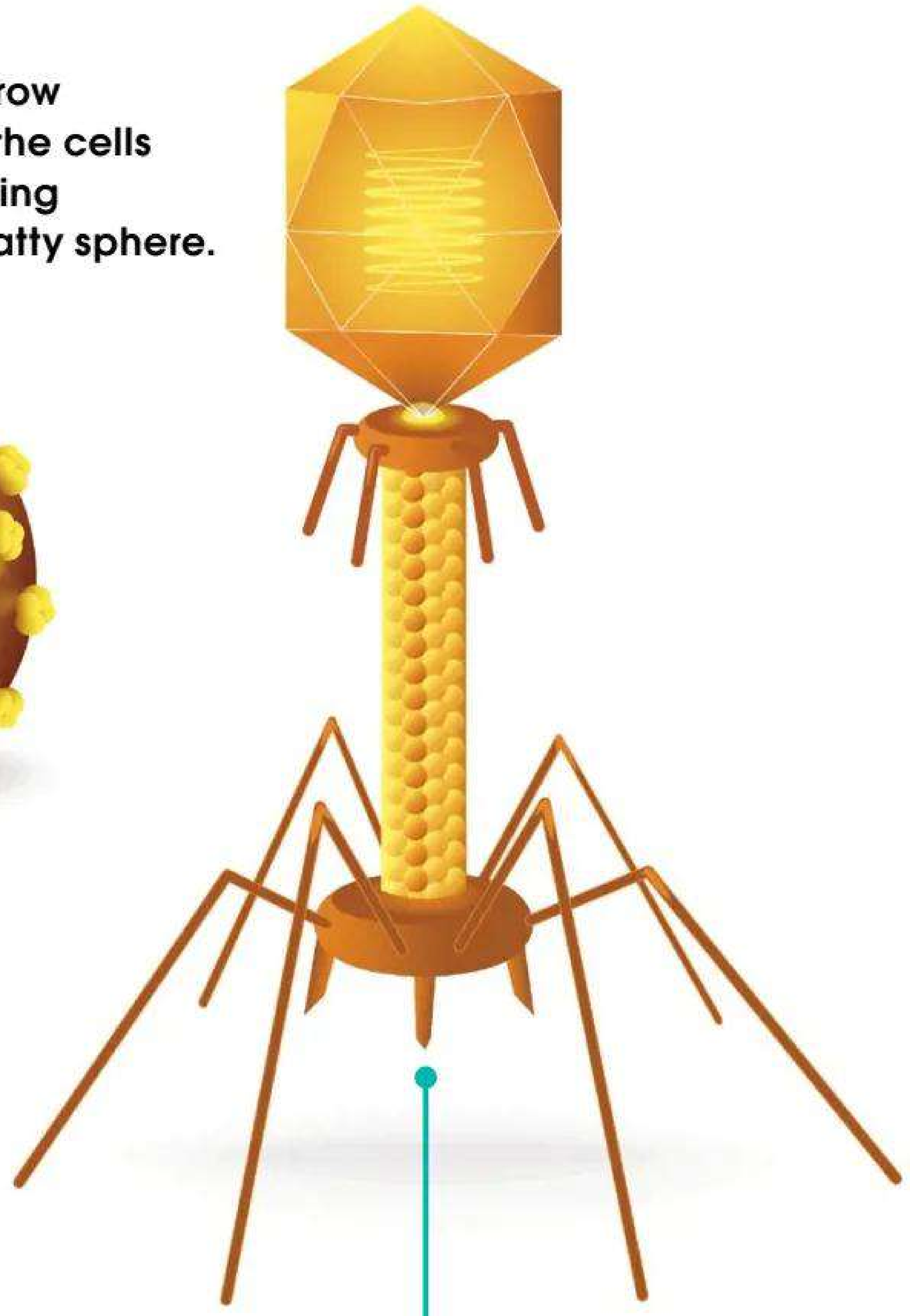
The outside of these viruses is a regular 3D structure, most often a 20-sided ball.

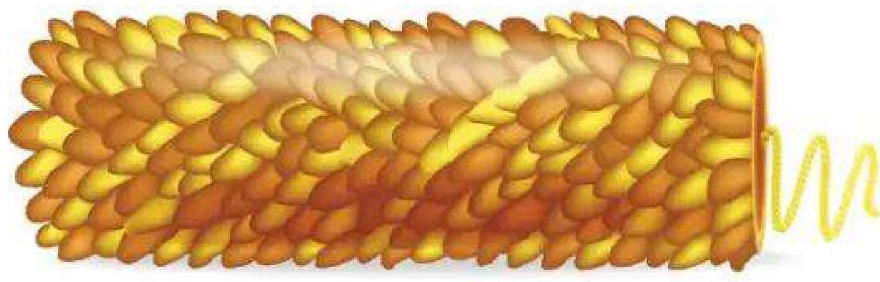


Spherical

These viruses borrow membrane from the cells they infect, covering themselves in a fatty sphere.







Helical

The genetic code of these viruses is covered in a twisted tube-shaped coat.

Complex

These viruses have irregular shapes and do not fit neatly into the other categories.

> "Viruses simply hijack other cells and turn them into virus factories"

Are viruses alive?

This is still a topic of debate among scientists. Viruses do not fit into our definitions of life, but they share some 'life-like' characteristics

ALIVE

"Viruses use the same molecular building blocks as other living organisms: RNA, DNA and protein"

"Viruses evolve and have made complex changes to their genetics to adapt to their unique environments"

"Lots of other parasitic organisms depend on others for survival and cannot exist on their own"

DEAD

"Viruses have a protective protein coat, but they do not have a membrane and are not cells"

"Viruses don't use any energy when they're floating between cells. They simply exist"

"Viruses cannot copy their own genetic code – they need living cells to do it for them"

called reverse transcriptase, which allows them to convert RNA into DNA inside a living cell.

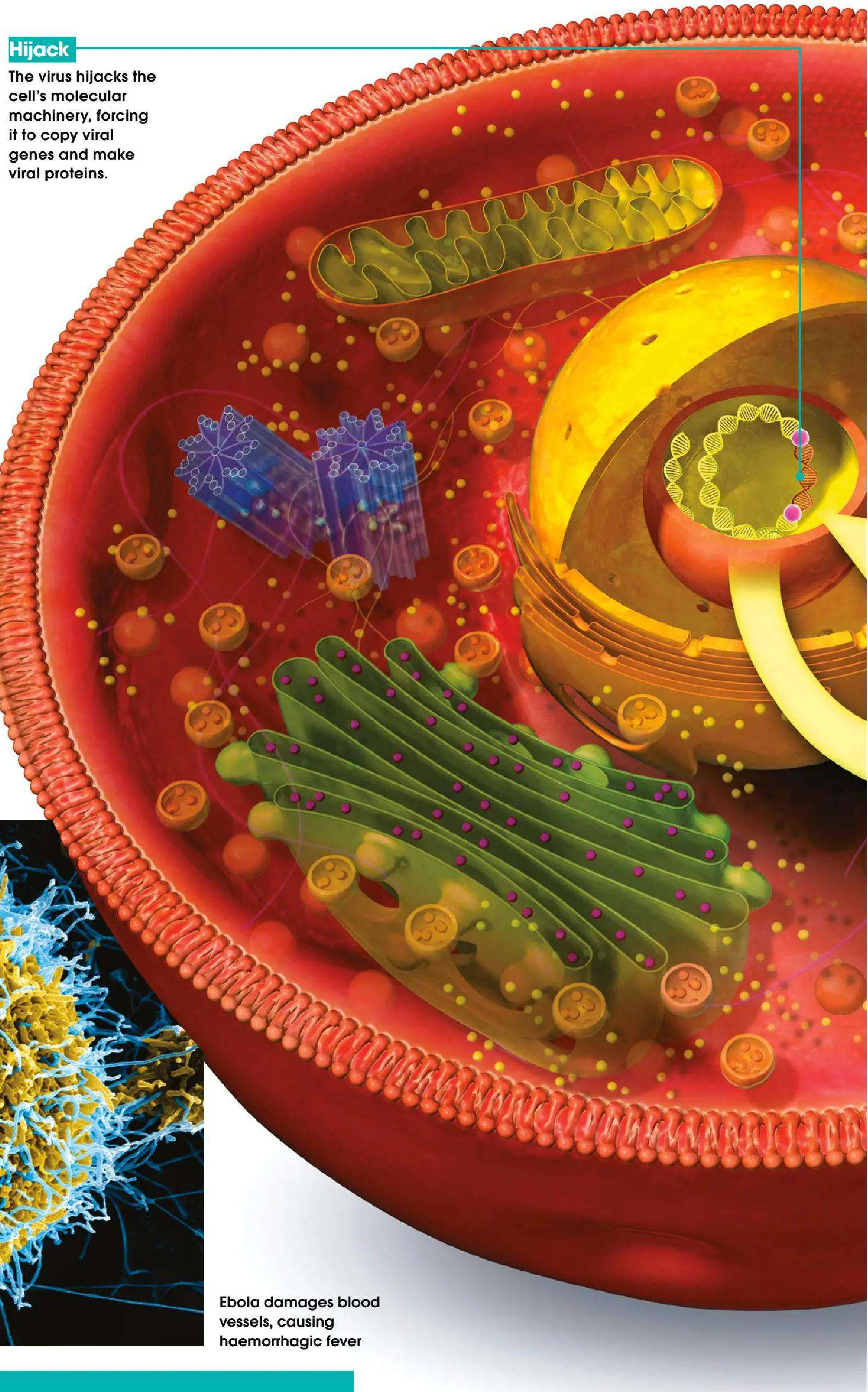
Genetic information is fragile, so to move from one cell to the next, viruses need a way to protect their code. Some of their most important genes provide the instructions to build proteins that make a protective coat called a capsid. The capsid proteins form repeating structures that lock together to make a 3D shape. This crystal-like patterning means that viruses only need a few genes to make a complete shield. Icosahedral capsids, for example, often contain small triangles made from just three proteins. These triangles slot together to make a 20-sided ball that covers the viral genome.

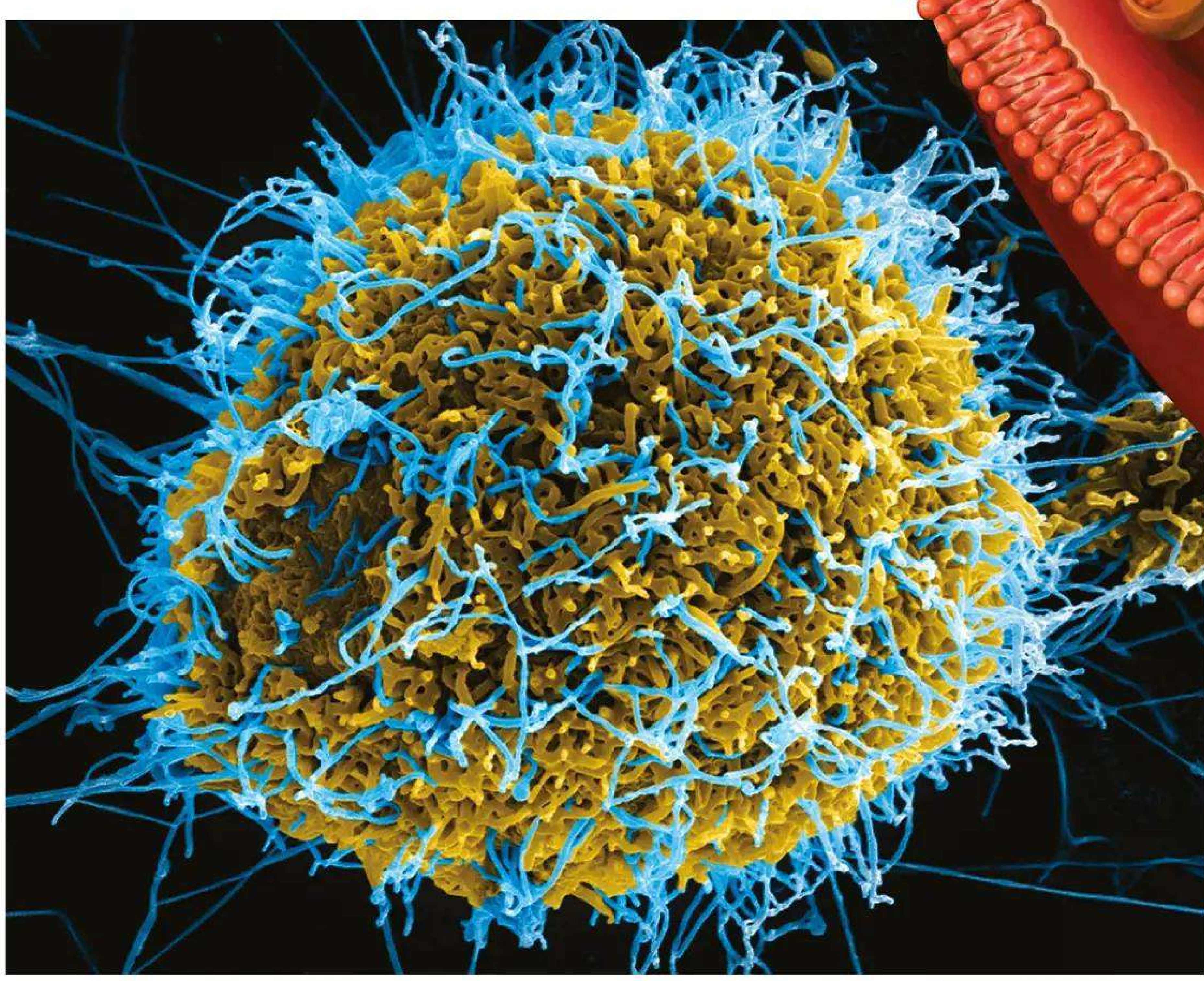
The infectious packages of capsid and genetic code can survive outside of cells, but they can't replicate on their own. Known as virions, these virus particles need to get back into cells to continue their lifecycle. They do this by attaching to molecules on the cell surface.

Proteins on the outside of the capsid interact with proteins on the outside of the cell. This attachment may change the shape of the virion itself, allowing the particle to fuse with the cell membrane. Alternatively, it might trick the cell into pulling the virus into a membrane-covered sphere known as an endosome. Once inside, enzymes carried by the virion – or from the cell itself – break down what's left of the capsid, releasing the genetic code into the cell. The viral genome then enters the cell's production line and quickly begins manufacturing three main types of protein.

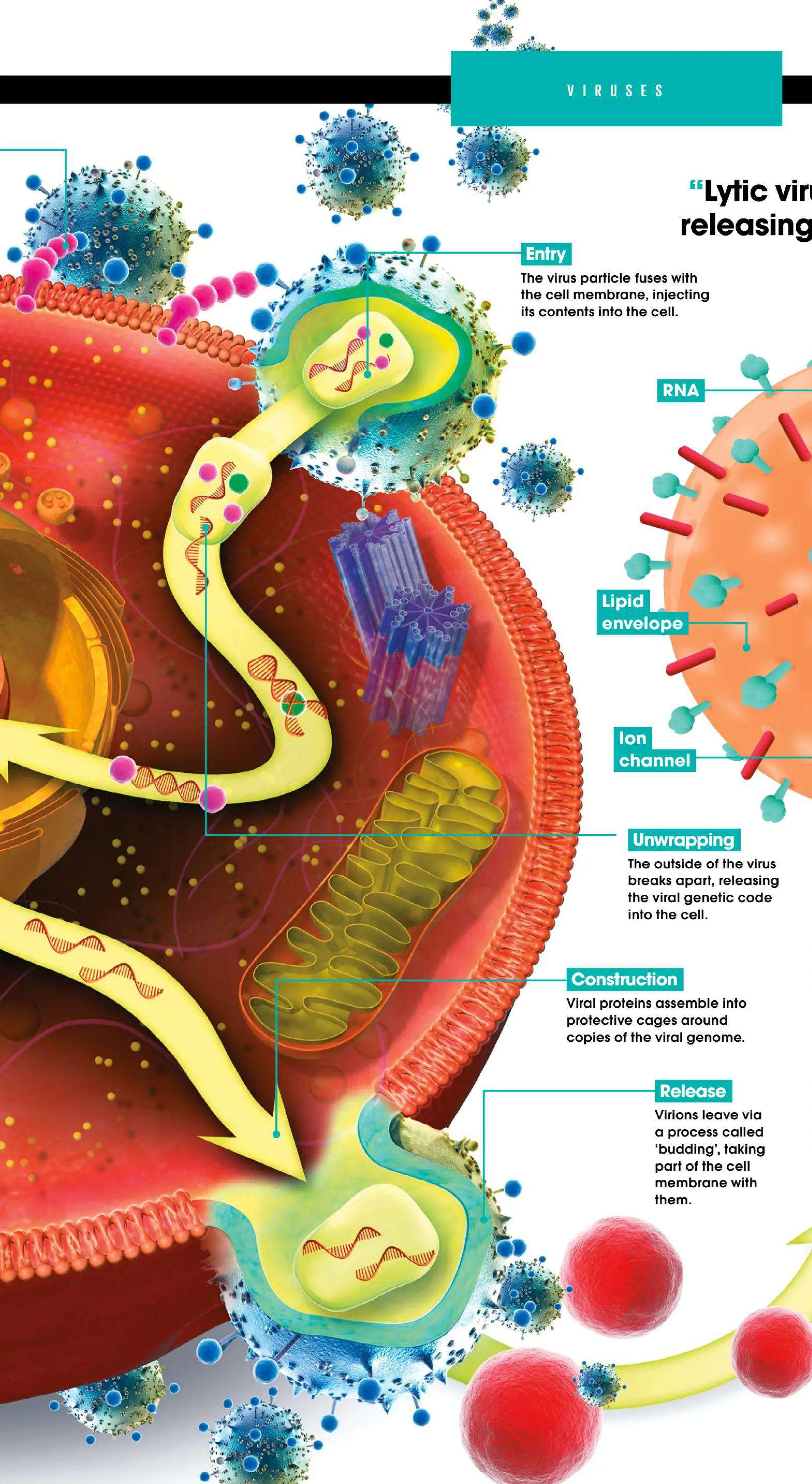
Virus production

These pathogens turn cells into miniature virus factories



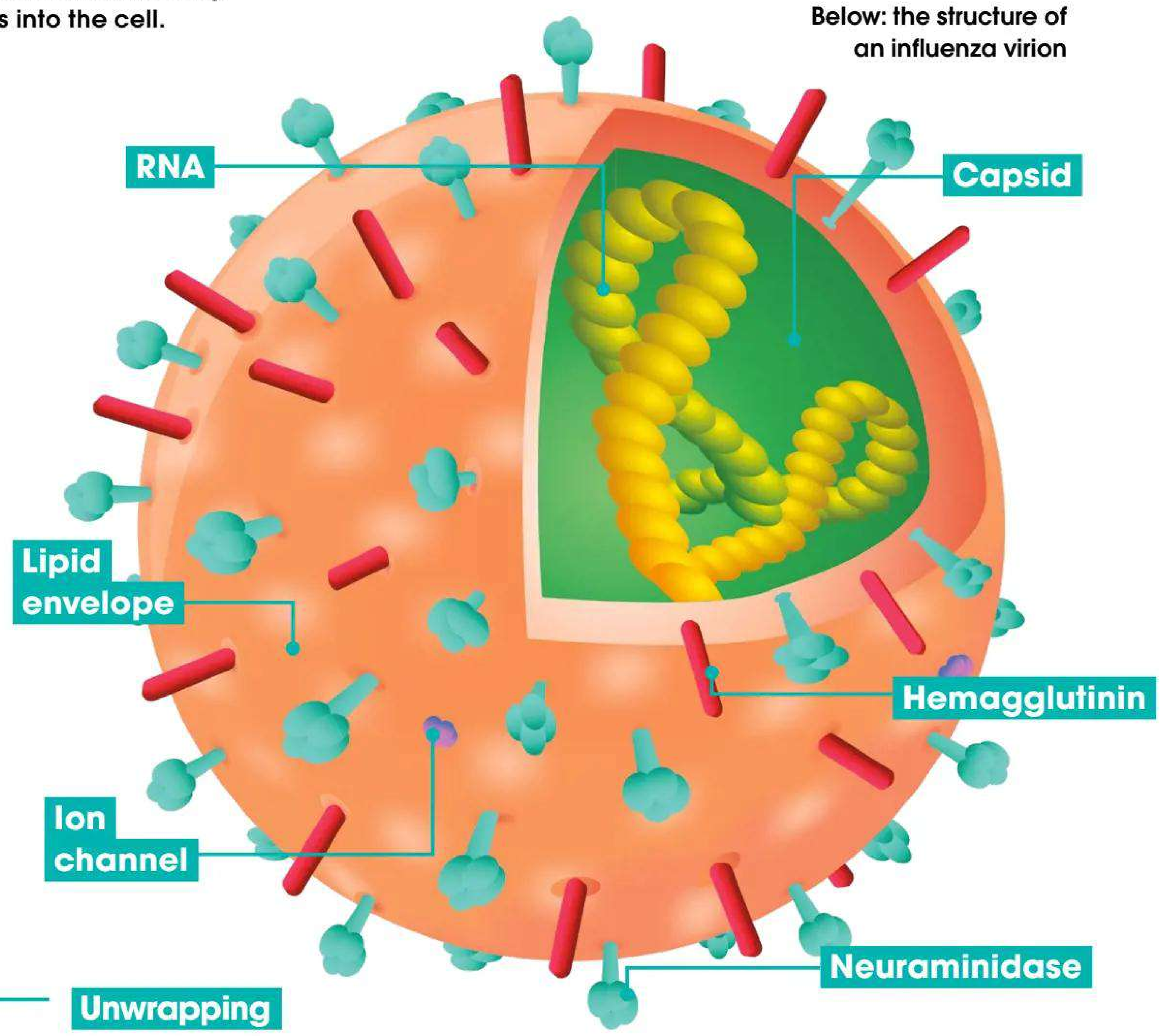


Ebola damages blood vessels, causing haemorrhagic fever



"Lytic viruses simply burst out, releasing all their virions in one huge pop"

Below: the structure of an influenza virion



The first are enzymes that enable the virus to construct more copies of its own genes. The second are proteins that interfere with the cell's normal manufacturing processes. The third type are the structural proteins that work to build new virus particles.

When the new virus particles are complete, the virus needs a way to release them to infect more cells. 'Lytic' viruses simply burst out, releasing all their virions in one huge pop and killing the cell in the process. 'Lysogenic' viruses release new virions one by one, allowing the host cell to survive and reproduce. Some viruses even stitch their genetic code into the code of their host, so that every time the cell divides, the new cells also get a copy of the viral genes. This allows viruses to remain inside cells for a long time, staying dormant and then reactivating later, a property known as latency.

Cells do attempt to defend themselves from this type of attack. They destroy loose genetic

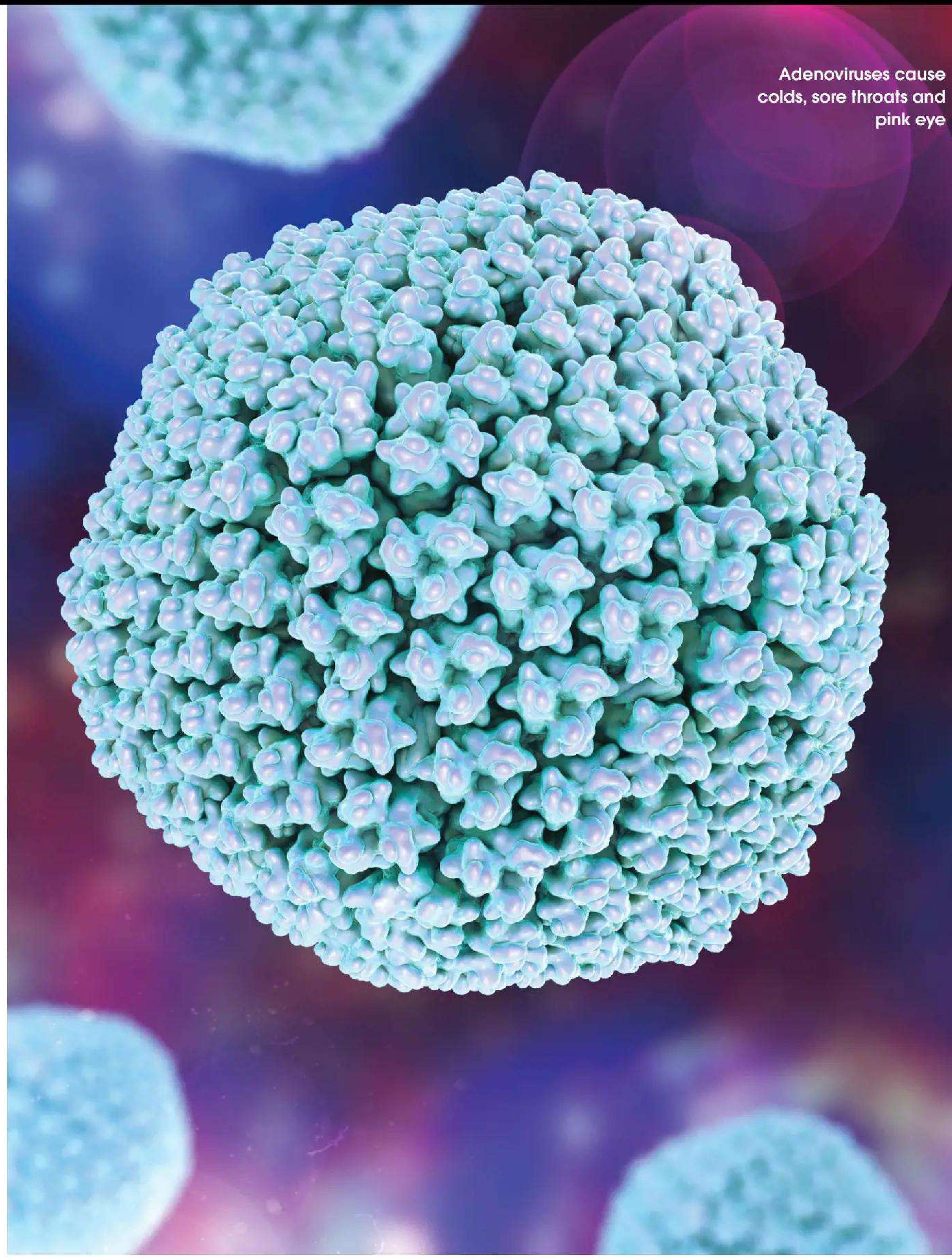
code and send signals to the immune system to let it know about the infection. But viruses have evolved ways to evade these defences – in the process, some have gained characteristics that harm their hosts, a property that is known as virulence.

Many viruses cause disease, diverting healthy cells away from their normal activities. The type of damage a virus does depends on the cells it infects, the way it interferes with molecular machines and the way it releases new virions. Some of the most serious problems arise when viruses infect immune cells, preventing the body from fighting back. Ebola, Marburg and HIV all harm the immune system.

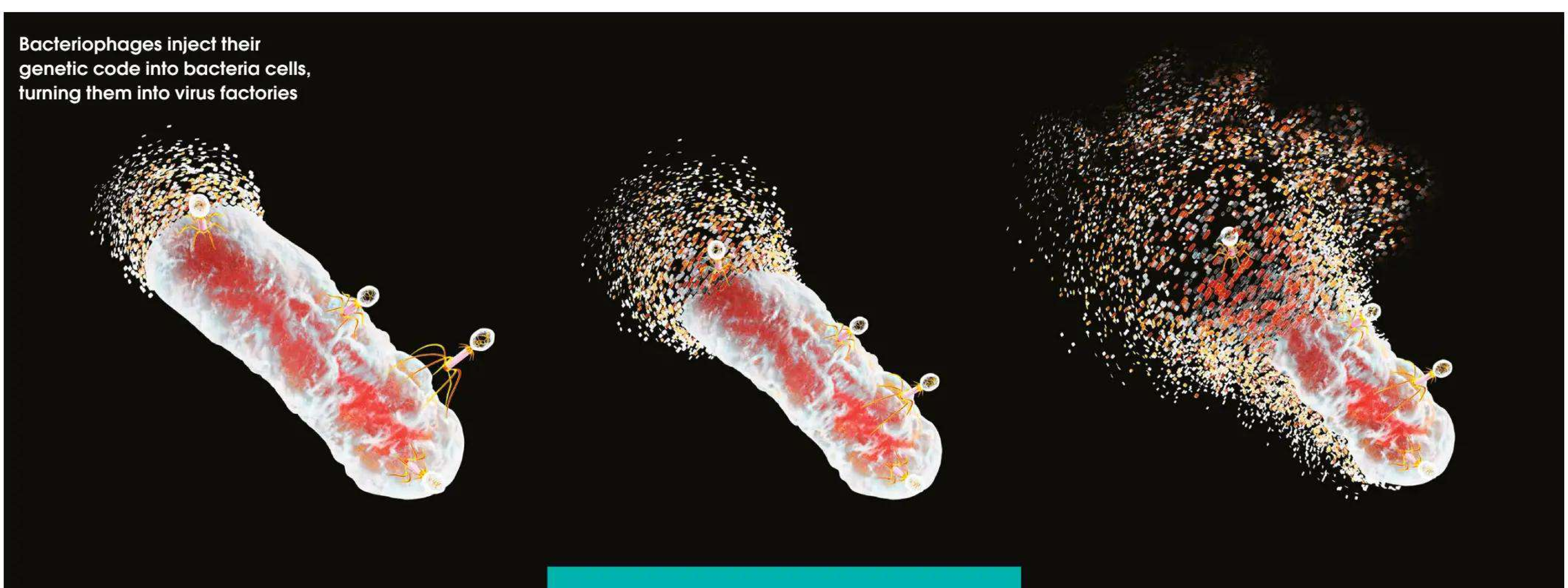
However, viruses aren't all bad; infections help to shape the way our bodies work. Studies of the human genome have revealed that around eight per cent of our genetic code actually came from viruses. Known as human endogenous retroviruses, or HERVs, they are easy to spot because they still carry the remnants of three viral genes: gag, pol and env. These genes belong to retroviruses, which stitch their genetic code into the genome of their host.

Retroviruses leave a permanent mark on DNA, and the results of ancient infections have been passed from parent to child for thousands of years. Evolution has gradually changed the sequence of these leftover viral genes, making them unable to produce new virions. Our bodies have found new uses for the code left behind.

One HERV, HERV-W, codes for proteins that would once have sat in the outer envelope of a virus, helping it to fuse with cells. We have adapted the code to make new proteins that help to fuse cell membranes together to form the placenta. Without the leftovers of ancient viral infections we wouldn't be here today.



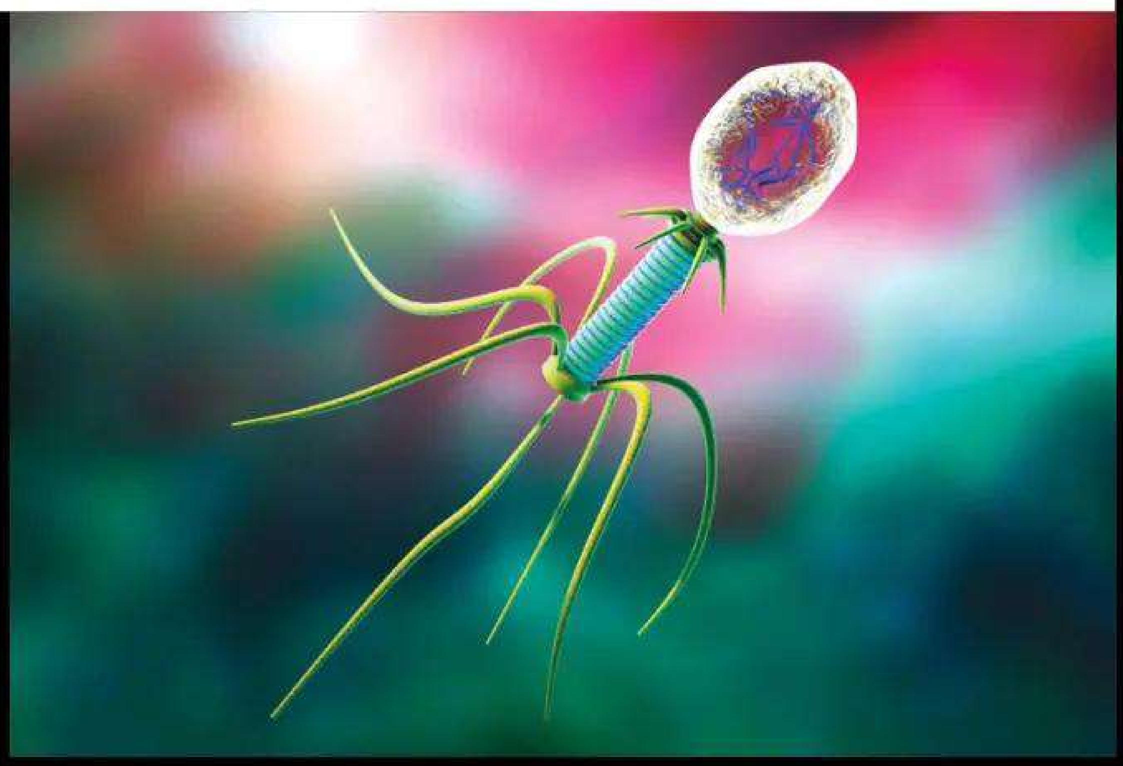
Adenoviruses cause colds, sore throats and pink eye



Bacteriophages inject their genetic code into bacteria cells, turning them into virus factories

Viral vectors

These tiny packets of genetic code are the most successful parasites in the world

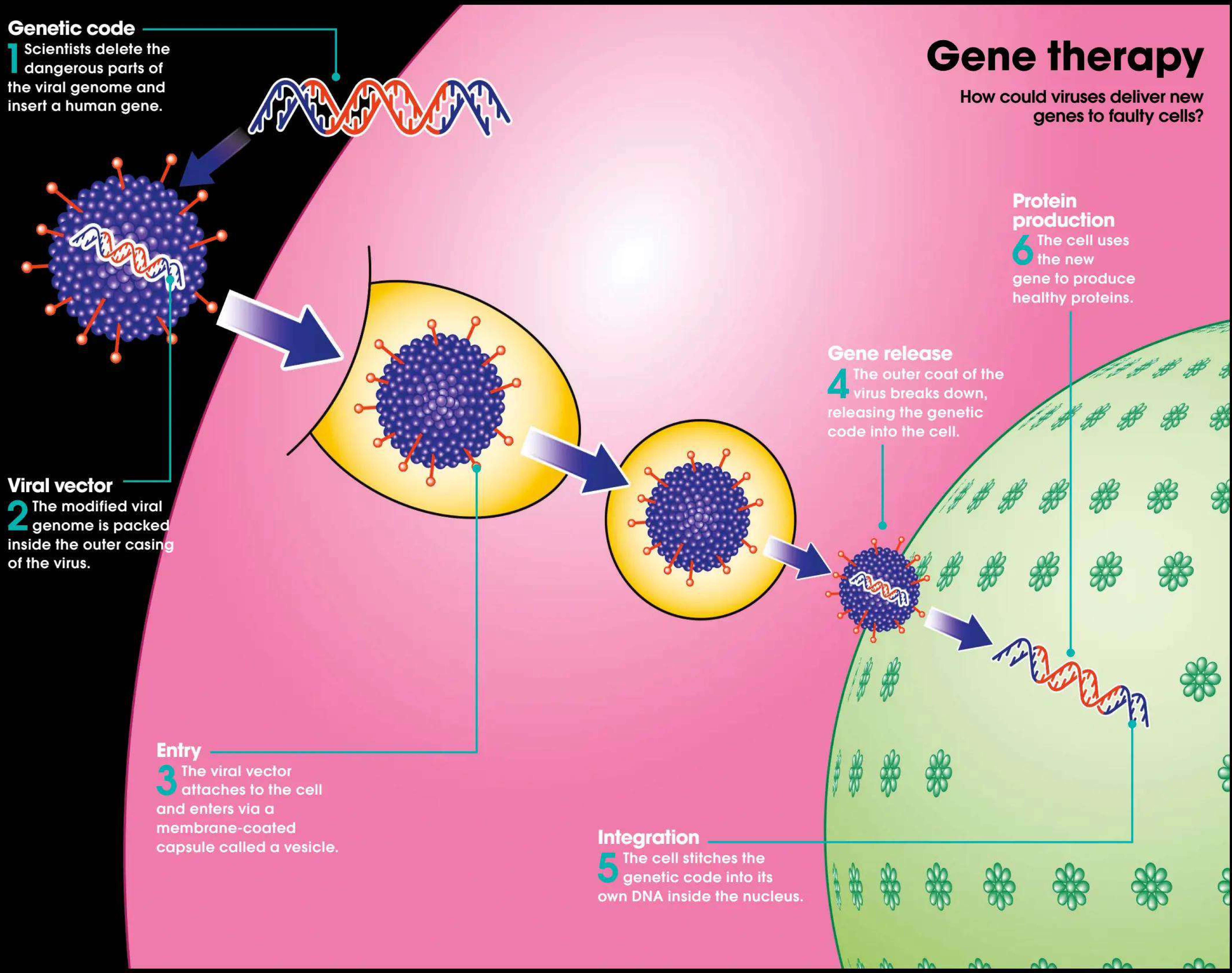


Viruses specialise in getting past cellular defences to deliver genetic information into cells, but in nature they often contain genes that cause disease. However, if we strip out these damaging stretches of code we could use the outer virus packaging as a way to deliver useful genes to damaged cells. This is the idea behind viral vectors.

The first step requires scientists to delete the parts of the viral genome that allow viruses to make copies of themselves. Then they add the code for different genes. When the modified virus infects a cell, it carries these new genes with it.

The most commonly used viruses for vector science are adenoviruses and retroviruses. Adenoviruses have a DNA-based genome and temporarily infect mammalian cells. The cells make viral proteins for a short time and then they go back to normal. Retroviruses are RNA-based and insert their genetic code into the genome of the cells they infect. This permanently changes the DNA of the cell, making it produce viral proteins forever.

Viral vectors allow scientists to find out what happens when cells gain the ability to make different proteins. They also have the potential to fix broken genes by delivering fresh genetic code to human cells. However, the technology may be dangerous because it's hard to control exactly where the cell puts the new genes. Research is ongoing to find out if we can safely use viruses for gene therapy.



The other senses

Discover the ten senses you never knew you had

The five classic human senses get all of the attention, so it might surprise you to know that there are several more senses working quietly in the background. Take something as simple as sitting down to eat your dinner. All five senses are active, taking in the sight and smell of the food on your plate, the taste and feel as you put it into your mouth, and the sound as you chew, but without your other senses, the experience would not be the same.

The simple act of sitting at the table and getting the food from the plate to your mouth is a sensory feat. You can't keep an eye on your limbs all the time, so the positions of your joints and the tension on your muscles is constantly measured, enabling you to eat without having to closely watch what you are doing. In order to stay balanced as you reach across the table, sensory information is quietly gathered by specialist structures in the inner ear.

Once the food is inside your mouth, one set of sensors provides information about the temperature, and another set of specialist nerves called nociceptors quickly alert you if the mouthful is dangerously hot or cold. At the same time, your blood and the fluid surrounding your central nervous system are monitored to make sure that levels of carbon dioxide and oxygen remain within normal limits, and your breathing rate is subconsciously adjusted.

As your stomach starts to fill up, stretch sensors feed back to the brain, turning down the signals that are telling you to keep eating, and when the part-digested food starts to hit your small intestine, sensors trigger the production of a hormone that flicks the switch telling you that you have had enough.

The build-up of waste products is also closely monitored, and long after your meal is completed, sensors will alert you when it is time to get rid of anything that is left over.

So while the traditional five senses are the ones on which we rely the most in our conscious interactions with the world around us, there are several more that are working quietly in the background as we go about our daily lives.

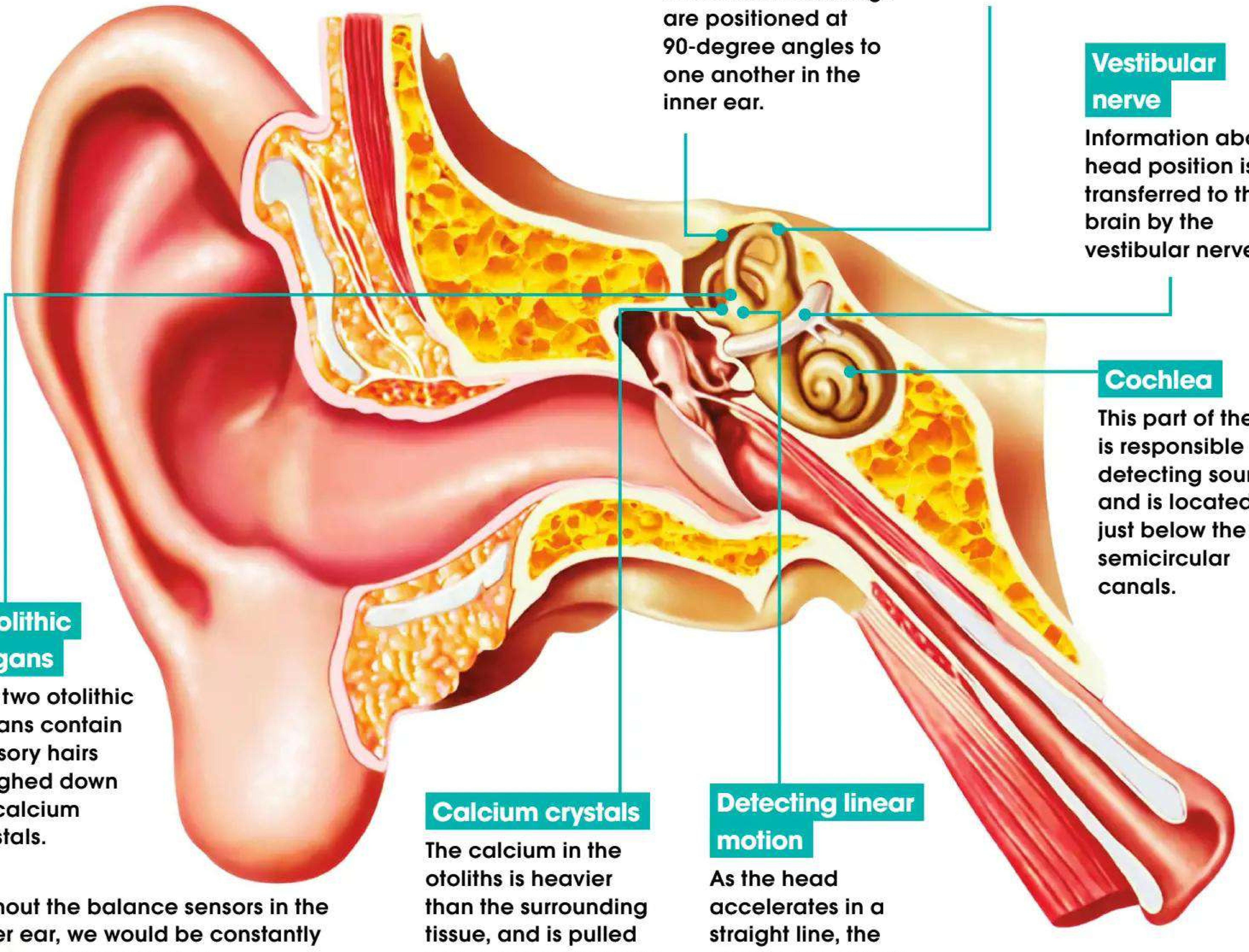
Balance

(equilibrioception)

Our sense of balance is handled by the vestibular system in the inner ear, and provides vital feedback about head position and movement. Inside the ear there are three semicircular canals; each is filled with fluid. At one end of each canal is a bulge supporting a series of sensitive hairs. As you move your head, the fluid moves too, bending the tiny hairs and sending information about head rotation to the brain. There are also two organs called otoliths on each side of the head. These contain sensory hairs weighed down by calcium crystals that help to tell which way is up.

The sense of balance

The inner ear contains specialised structures that detect head movements



Semicircular canals

Three fluid-filled rings are positioned at 90-degree angles to one another in the inner ear.

Detecting head rotation

As the head rotates, the fluid in the semicircular canals moves.

Vestibular nerve

Information about head position is transferred to the brain by the vestibular nerve.

Cochlea

This part of the ear is responsible for detecting sound, and is located just below the semicircular canals.

Otolithic organs

The two otolithic organs contain sensory hairs weighed down by calcium crystals.

Calcium crystals

The calcium in the otoliths is heavier than the surrounding tissue, and is pulled by the force of gravity as the head moves.

Detecting linear motion

As the head accelerates in a straight line, the otoliths are able to detect the movement.

Without the balance sensors in the inner ear, we would be constantly dizzy and disorientated

Without proprioception, you wouldn't be able to touch your nose with your eyes closed

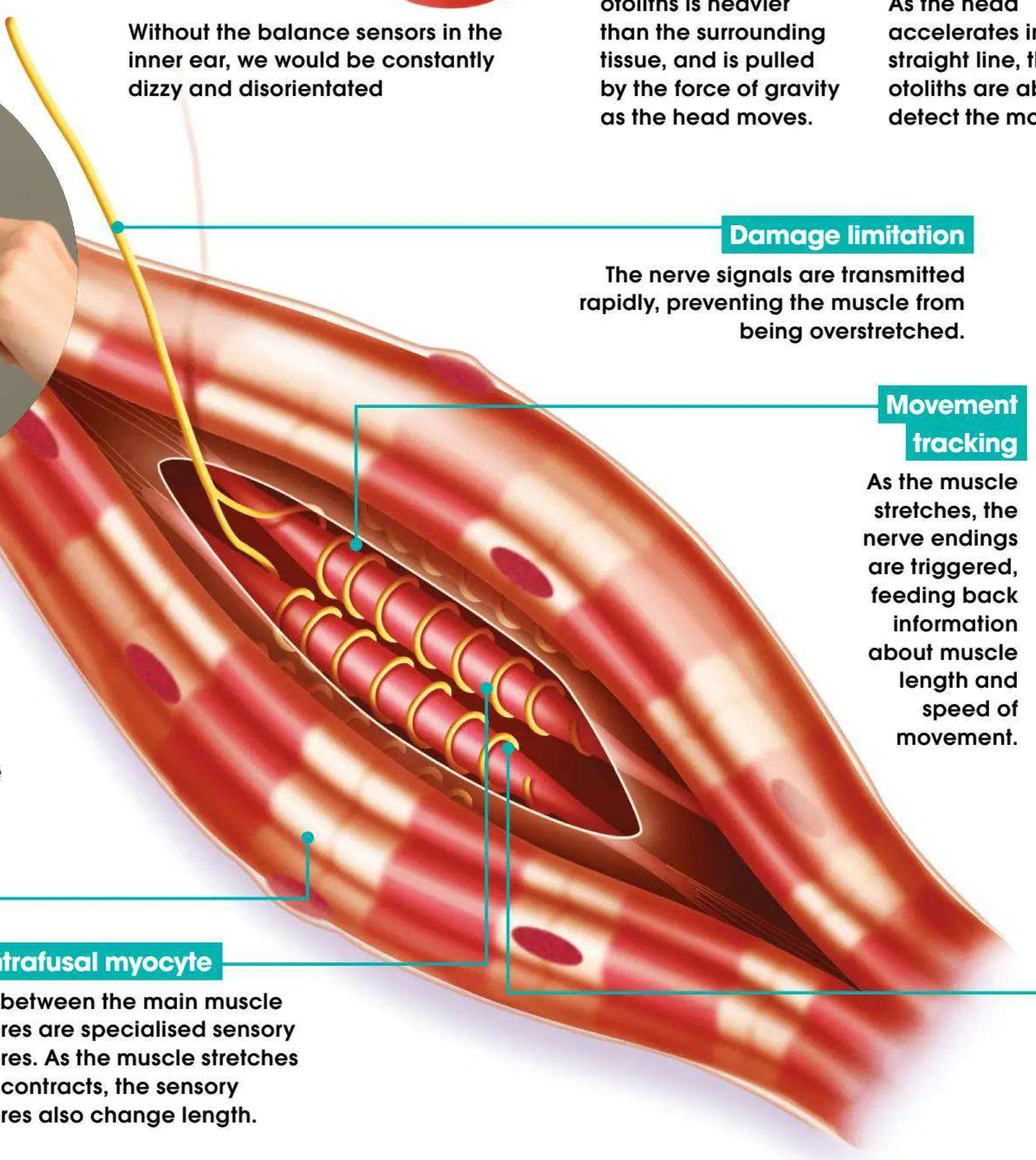
Movement

(proprioception)

Even the simplest movements would be a challenge without this sense; proprioception allows us to keep track of the position of our bodies in space without looking. This enables us to make the tiny adjustments that keep us from falling over when we are standing still, helps us to judge the distance each time we take a step, and allows us to coordinate complex movements like riding a bike or playing the piano. The receptors responsible are found in the joints, muscles and skin, and help to relay information about the angle and position of each joint, and the tension on our tendons and muscles, providing the brain with constant feedback.

Keeping track

Specialised fibres inside the muscle are able to detect stretch and movement



Damage limitation

The nerve signals are transmitted rapidly, preventing the muscle from being overstretched.

Movement tracking

As the muscle stretches, the nerve endings are triggered, feeding back information about muscle length and speed of movement.

Extrafusal myocyte

The main muscle fibres are responsible for contraction, controlled by incoming nerve signals.

Intrafusal myocyte

In-between the main muscle fibres are specialised sensory fibres. As the muscle stretches or contracts, the sensory fibres also change length.

Wrapped nerve cells

The sensory muscle fibres are wrapped in a coil of branching nerve endings.

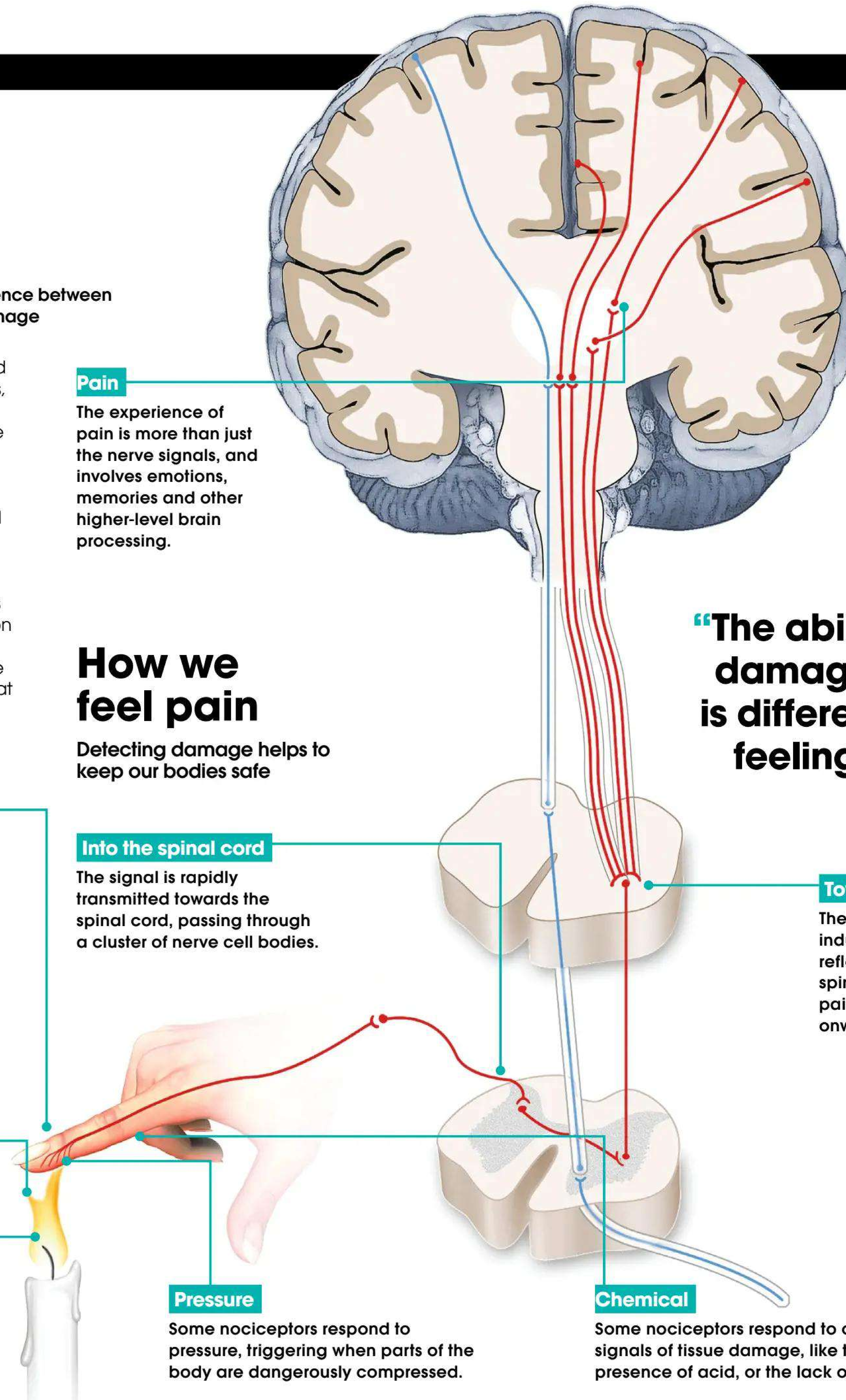
Pain
(nociception)

This sense allows us to tell the difference between a harmless touch and potential damage

Specialised nerve endings called nociceptors are found in the skin and organs. Unlike normal sensory nerves, these are not activated by low-level stimulation, and instead wait until the temperature, pressure or level of a toxic substance is enough to cause the body harm. Activation of these nerves can trigger a swift withdrawal reflex, prompting us to move away from the harmful stimulus, and in the long term it acts as a deterrent, teaching us to avoid whatever it was that caused the unpleasant sensation in the first place. The ability to sense damaging stimuli is different from the feeling of pain, and the sensation that we are all familiar with involves a significant amount of further processing in the brain.

How we feel pain

Detecting damage helps to keep our bodies safe



Pain

The experience of pain is more than just the nerve signals, and involves emotions, memories and other higher-level brain processing.

Pain receptor

Nociceptors are only activated if tissue damage is imminent, alerting the body to potential danger.

Into the spinal cord

The signal is rapidly transmitted towards the spinal cord, passing through a cluster of nerve cell bodies.

Towards the brain

The incoming signal can induce a rapid withdrawal reflex just by reaching the spinal cord, but the feeling of pain relies on signals travelling onwards to the brain.

Heat

Some nerves respond specifically to heat, becoming active at temperatures above 40-45 degrees Celsius (104-113 degrees Fahrenheit).

Cold

Other nerves respond to cold temperatures, and start to fire when temperatures drop below five degrees Celsius (41 degrees Fahrenheit).

Pressure

Some nociceptors respond to pressure, triggering when parts of the body are dangerously compressed.

Chemical

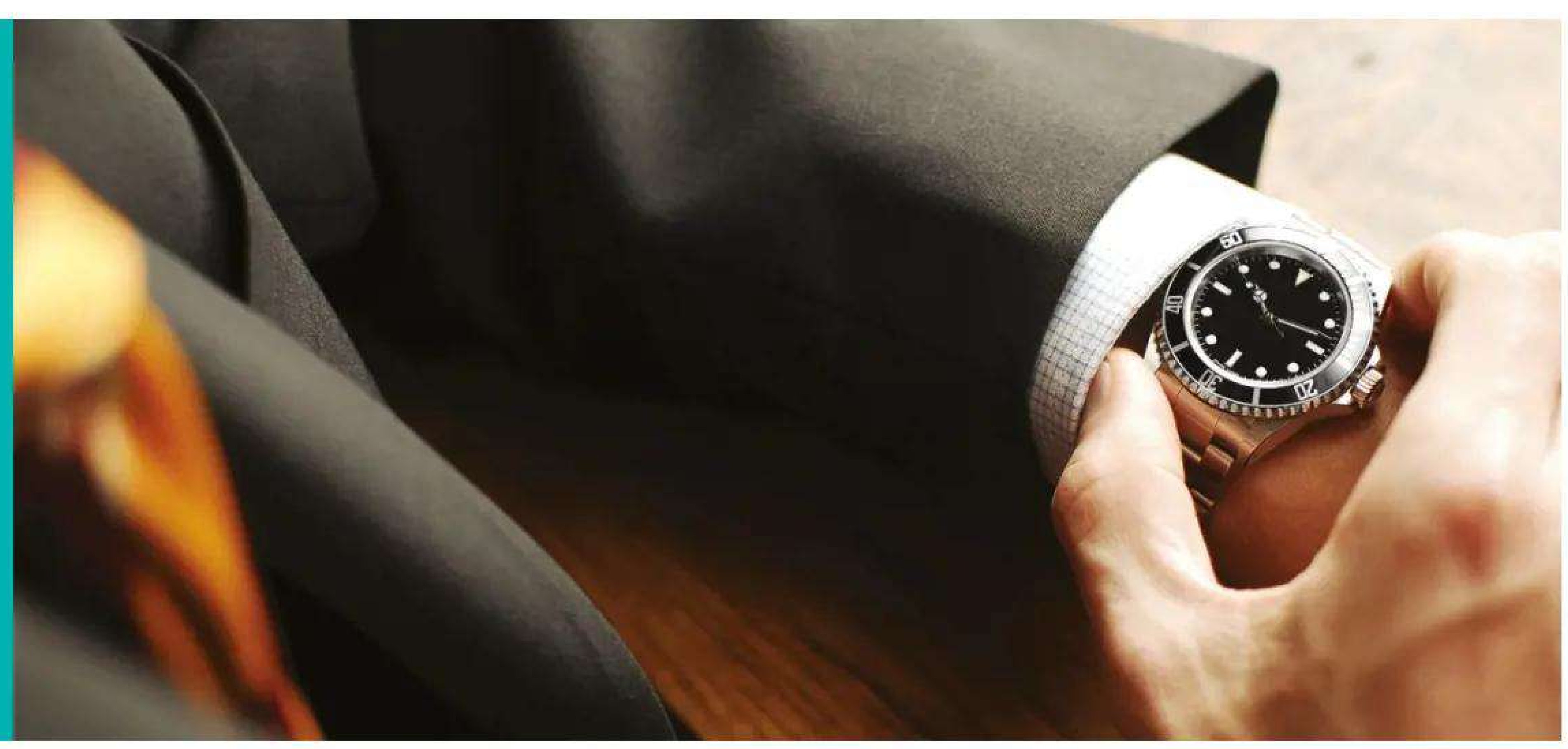
Some nociceptors respond to chemical signals of tissue damage, like the presence of acid, or the lack of oxygen.

> **"The ability to sense damaging stimuli is different from the feeling of pain"**

Pain (nociception)

Internal clocks help us to keep track of time

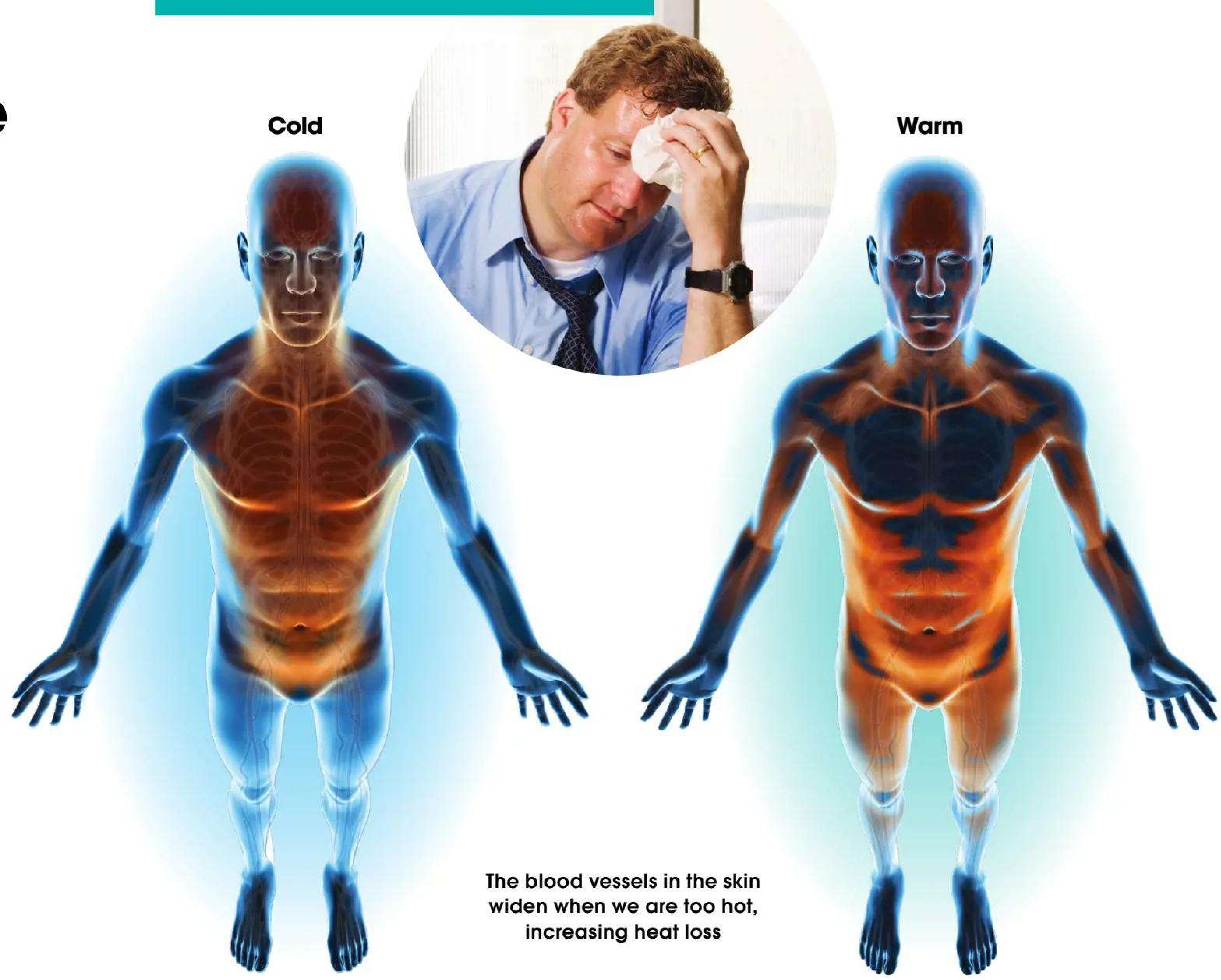
Even without a watch, we have a sense of the passage of time, but our body clock is not like any normal timepiece. The suprachiasmatic nucleus in the brain is the master clock, and it governs our daily cycle, or circadian rhythm. This 24-hour clock controls daily peaks and troughs in our hormone levels, influencing many behaviours, from eating to sleeping. For shorter tasks, scientists think that we might have several internal stopwatches keeping time inside our brains. As yet, the parts of the brain responsible for keeping these rhythms have not been discovered.



Temperature
(thermoception)

An internal thermostat keeps our body temperature at a constant 37°C (98.6°F)

It is crucial for our bodies to be able to detect heat and cold, firstly to ensure that our internal organs are kept at the right temperature to function properly, and secondly to prevent us being damaged by extremes. We are able to detect the temperature of our extremities by a series of nerves in the skin, while our core body temperature is monitored by a part of the brain known as the hypothalamus.
As warm-blooded animals, we generate huge amounts of heat as we burn sugars to release energy. This helps to keep us warm, but in order to maintain a constant temperature, adjustments need to be made continually to make up for changes in the environment or changes in our level of activity. For immediate changes in body temperature, the brain orders the body to shiver or sweat, and for more long-term regulation, the production of thyroid hormone is ramped up or down, altering the rate at which we burn sugars and generate heat.



The blood vessels in the skin widen when we are too hot, increasing heat loss

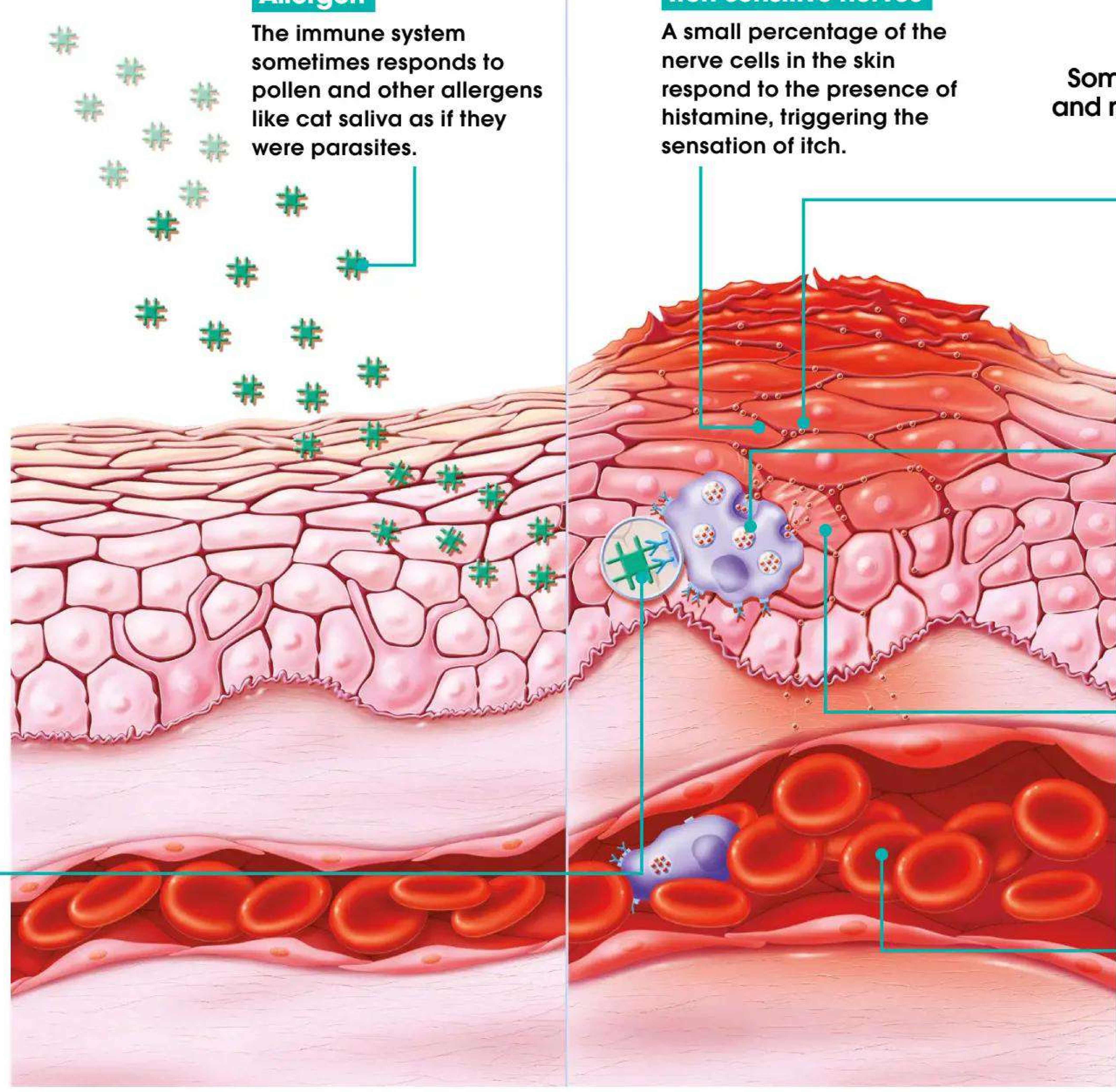
Itchiness

This unusual sensation is closely related to pain

Itchiness is the body's way of alerting us to parasites and irritants. It prompts a reflex scratch response, which scientists think is to draw our attention to that area of the body so any irritant can be eliminated. The exact science of itching is still unclear, but one of the most well studied culprits is a molecule known as histamine. Parasites like biting insects and worms often produce chemicals known as proteases, which help them to break through the barrier of the skin. These proteases trigger white blood cells to release histamine, which in turn activates our body's itch-sensitive nerve cells.

Allergic itch

Sometimes the body gets it wrong and releases histamine in response to harmless allergens



Allergen
The immune system sometimes responds to pollen and other allergens like cat saliva as if they were parasites.

Itch-sensitive nerves
A small percentage of the nerve cells in the skin respond to the presence of histamine, triggering the sensation of itch.

Extra sensitive
Other chemicals released during the inflammatory response sensitise the nerve endings, making them fire more easily and magnifying the sensation of itchiness.

Mast cell
These specialised immune cells behave like sentry towers in the skin. Their normal function is to respond rapidly to the presence of parasites.

Histamine
This small molecule is responsible for the itchiness associated with allergic reactions.

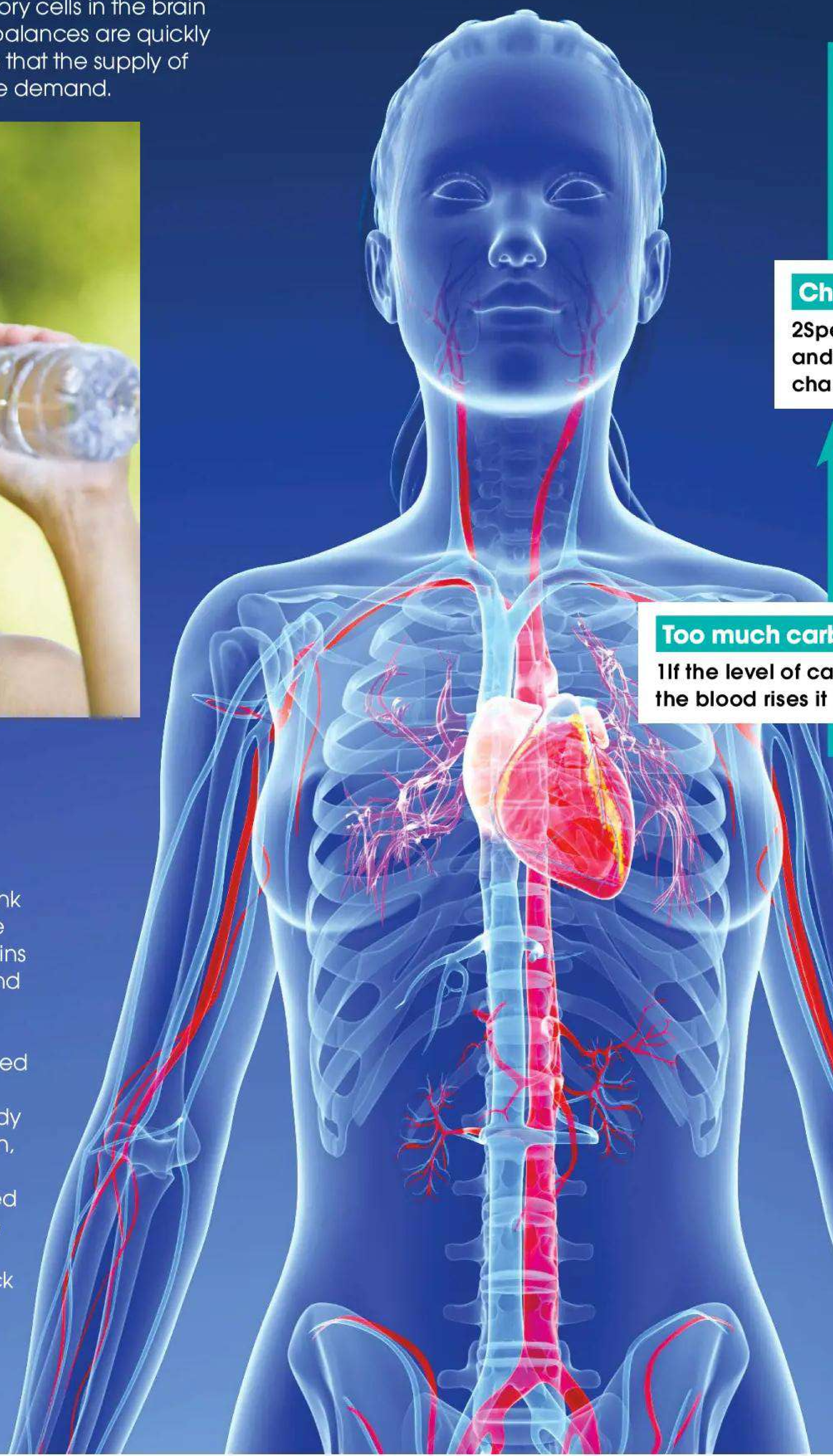
Allergen detection
The immune system sometimes mistakenly produces antibodies to attack harmless allergens. Mast cells then use these antibodies to detect when more allergens arrive.

Leaky vessels
Histamine also makes local blood vessels leaky, allowing more white blood cells to enter the area.

Internal sensors

Specialist sensory cells inside the body supply the brain with information about vital systems

We are all familiar with the senses that allow us to interact with our external environment, but behind the scenes, we need to constantly keep track of events happening on the inside. If we didn't, our tissues would quickly run out of fuel and oxygen, and waste products would start to build up. The state of the body is constantly monitored by specialised sensory cells in the brain and organ systems, ensuring that any imbalances are quickly noticed and corrected, helping to ensure that the supply of food, water and oxygen always meets the demand.



Thirst

Sensing the water level in our bodies prevents dangerous dehydration

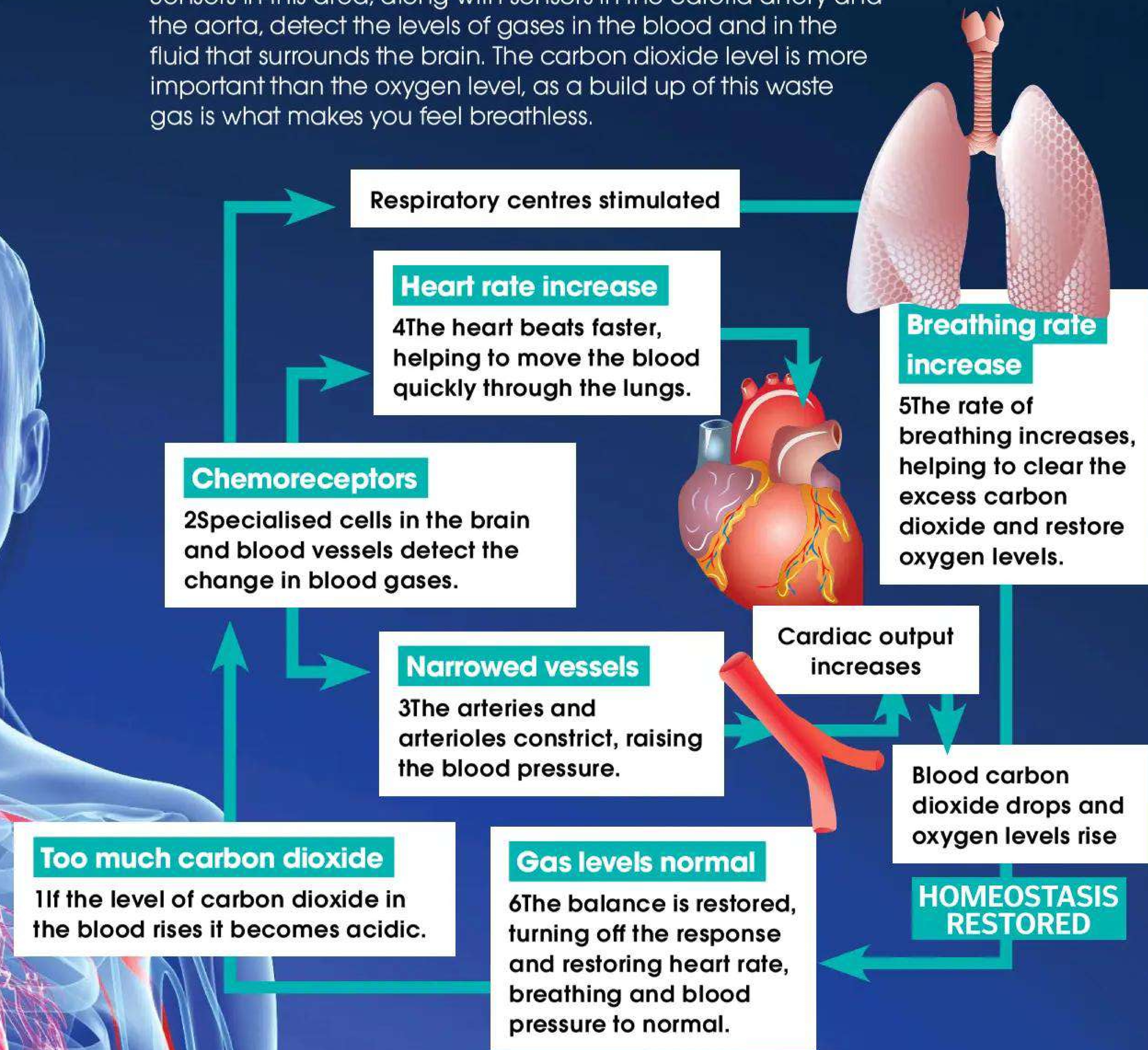
The ability to detect when we need to drink is crucial for survival. When we don't have enough water, the salts, sugars and proteins inside us become more concentrated, and function starts to decline.

Minute changes in water level are detected by special cells in the brain called osmoreceptors, triggering the feeling of thirst. To prevent further water loss, the body releases a hormone known as vasopressin, which acts on the kidneys to stop water being excreted as urine. A hormone called angiotensin is also produced, making the blood vessels constrict and raising the blood pressure to compensate for the lack of water until more arrives.

Breathing

The ability to sense blood gases helps to keep oxygen and carbon dioxide levels normal

Breathing is controlled by the respiratory centres in the brain. Sensors in this area, along with sensors in the carotid artery and the aorta, detect the levels of gases in the blood and in the fluid that surrounds the brain. The carbon dioxide level is more important than the oxygen level, as a build up of this waste gas is what makes you feel breathless.

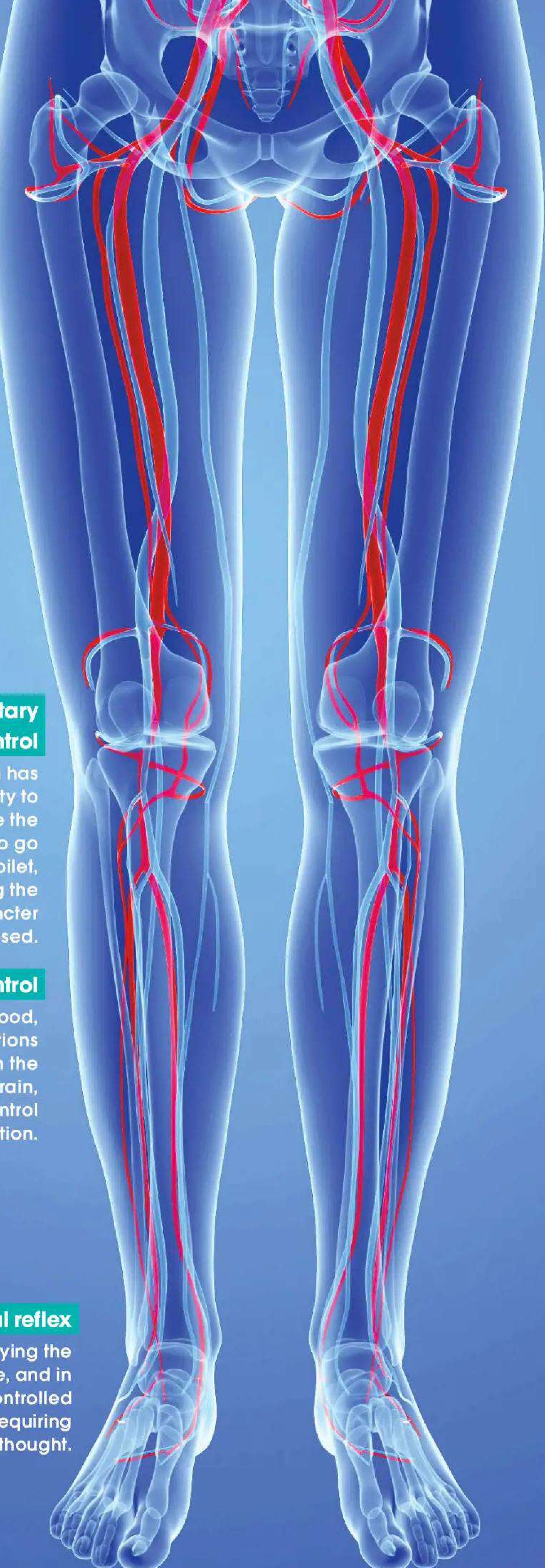


Hunger and fullness

Digestive sensors help to prevent us overeating, but they are easy to ignore

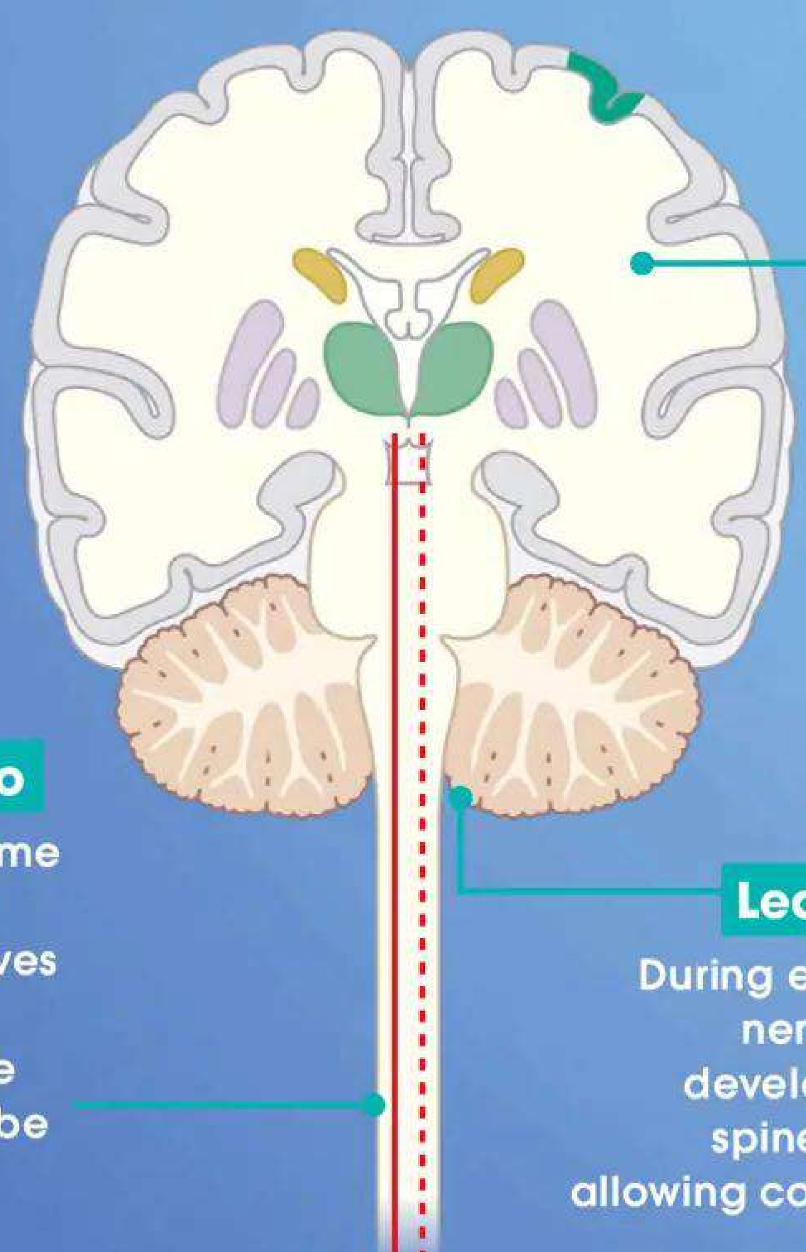
The feeling of hunger is controlled by a part of the brain called the hypothalamus. It produces two types of molecules: orexigens, which make you feel hungry; and anorexigens, which make you feel full. The hypothalamus decides which molecules to produce based on information sent by the digestive system.

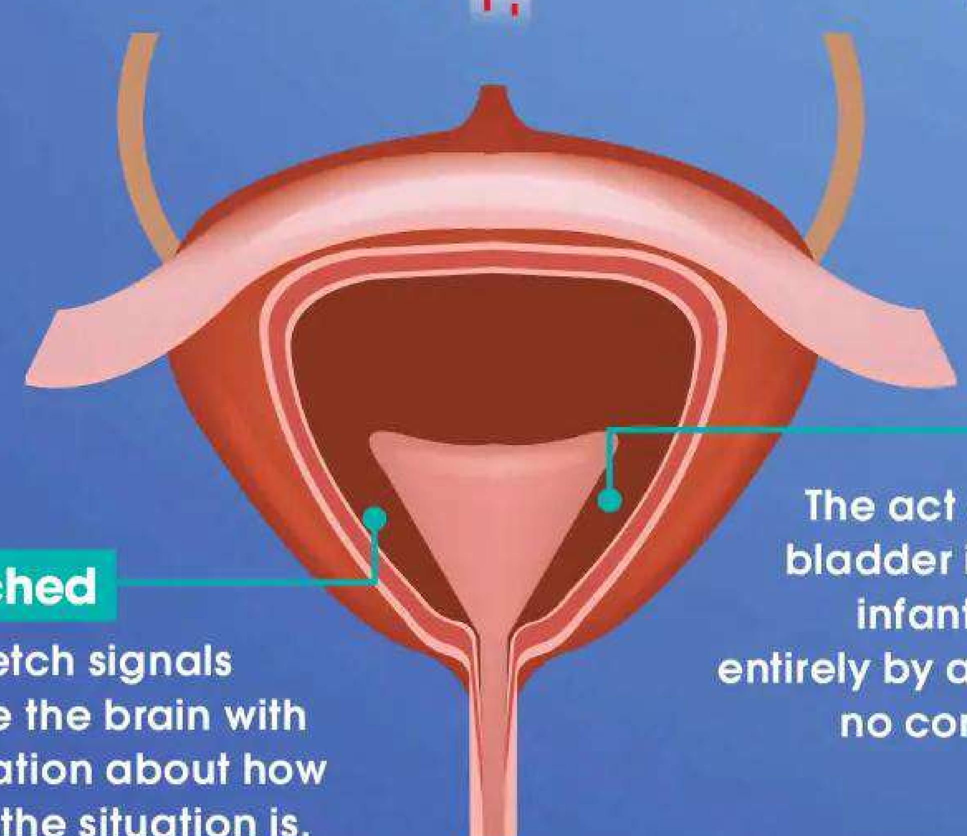
When you haven't eaten for a while, the top part of the stomach starts to produce a molecule called ghrelin, signalling to the hypothalamus that you need to take in more food. After a meal, stretch receptors in your stomach help to signal that you are full, and when fat and protein start to enter the first part of the small intestine, a molecule called cholecystokinin (CCK) helps to switch the hungry feeling off.



Control of waste disposal

Bladder emptying is timed using a specialised sense of touch

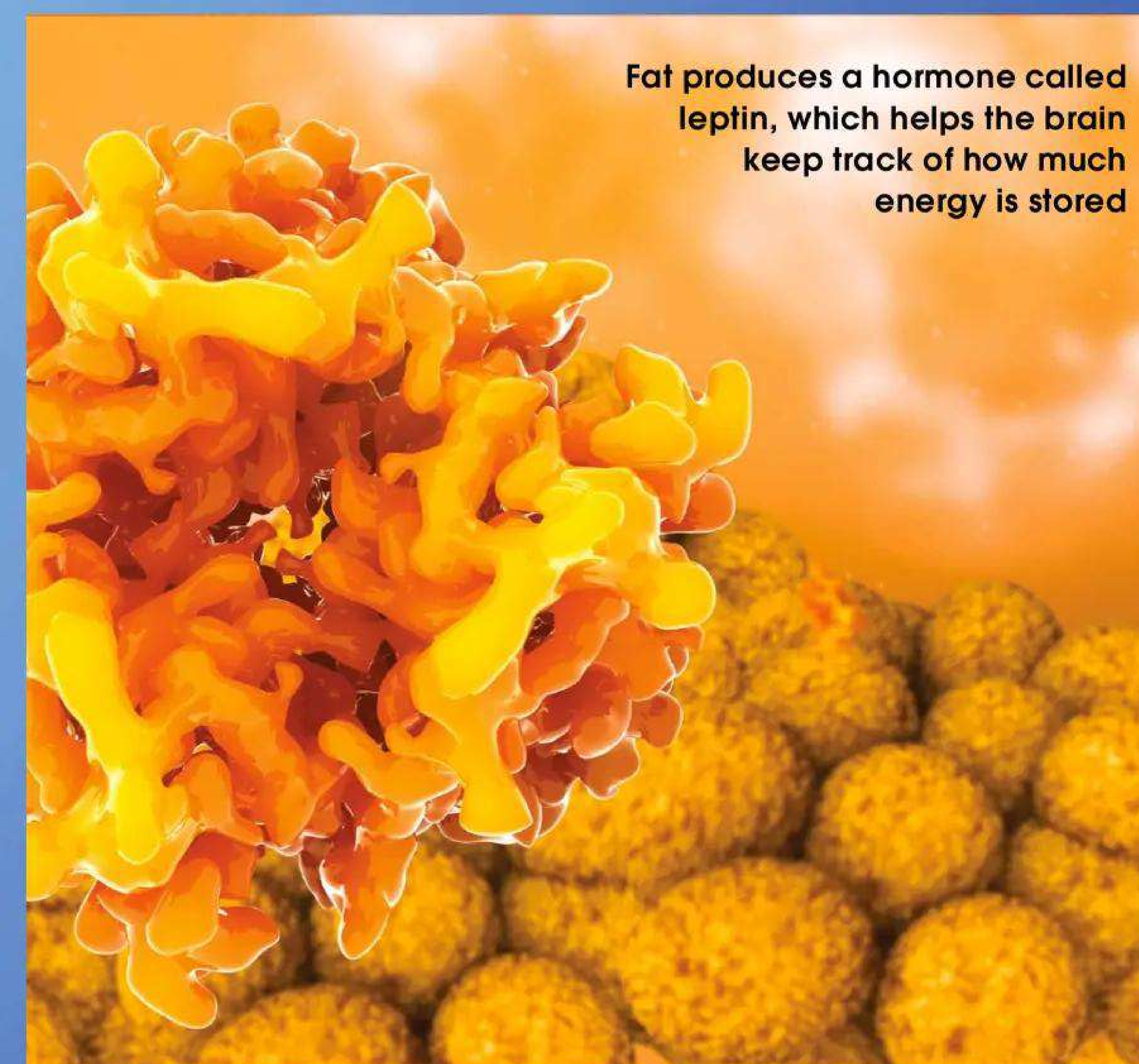




Excretion

Internal sensors help to time the elimination of waste products from the body

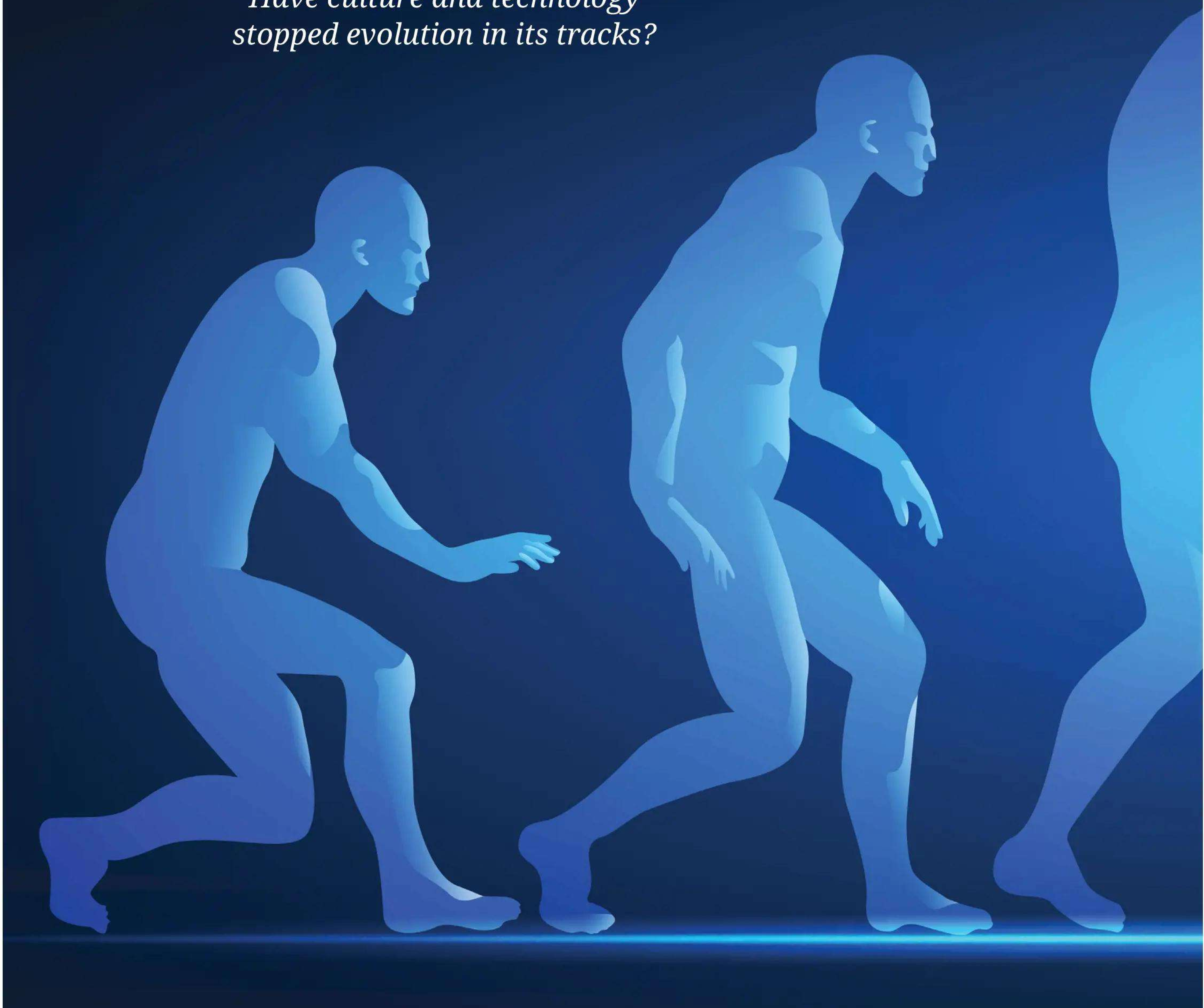
It is vital to remove waste products from the body before they start to build up, and there are several internal systems responsible for sensing, processing, and removing waste. Some leave via the lungs, some via the back passage, and some via the bladder.


Fat produces a hormone called leptin, which helps the brain keep track of how much energy is stored

"The state of the body is constantly monitored by specialised sensory cells"

Are we still evolving?

Have culture and technology stopped evolution in its tracks?



Every human alive today can trace their ancestry back to east Africa around 200,000 years ago – DNA from a single woman still exists in every one of our cells. At the time, the human population was tiny, and her descendants are the only ones still alive today. They spread across the continent 100,000 years ago before radiating out in waves across the world. Scientists know the mother of humanity as mitochondrial Eve.

We may have dispersed, but the genetic differences between us are surprisingly small. There is no major distinction between people living on different continents or people of different races. In fact, there are more genetic differences between subspecies of chimpanzee. This similarity makes people question whether we've stopped evolving completely.

Evolution relies on a few key ingredients. Every generation, an organism makes more individuals than are able to survive. There are differences between those individuals, known as phenotypic variation. The cause of those differences, genes or genotype, are heritable, meaning that they can pass from one generation to the next. Some traits are better suited to the current environment than others. Individuals with those traits are more likely to survive and reproduce, passing the genes for their traits on to the next generation.

New traits enter populations in three main ways, the most well-known of which is mutation. When we make sperm or eggs, cells in our reproductive organs copy their DNA. This process is error-prone, so every time it happens

Evolution depends on changes in culture and science

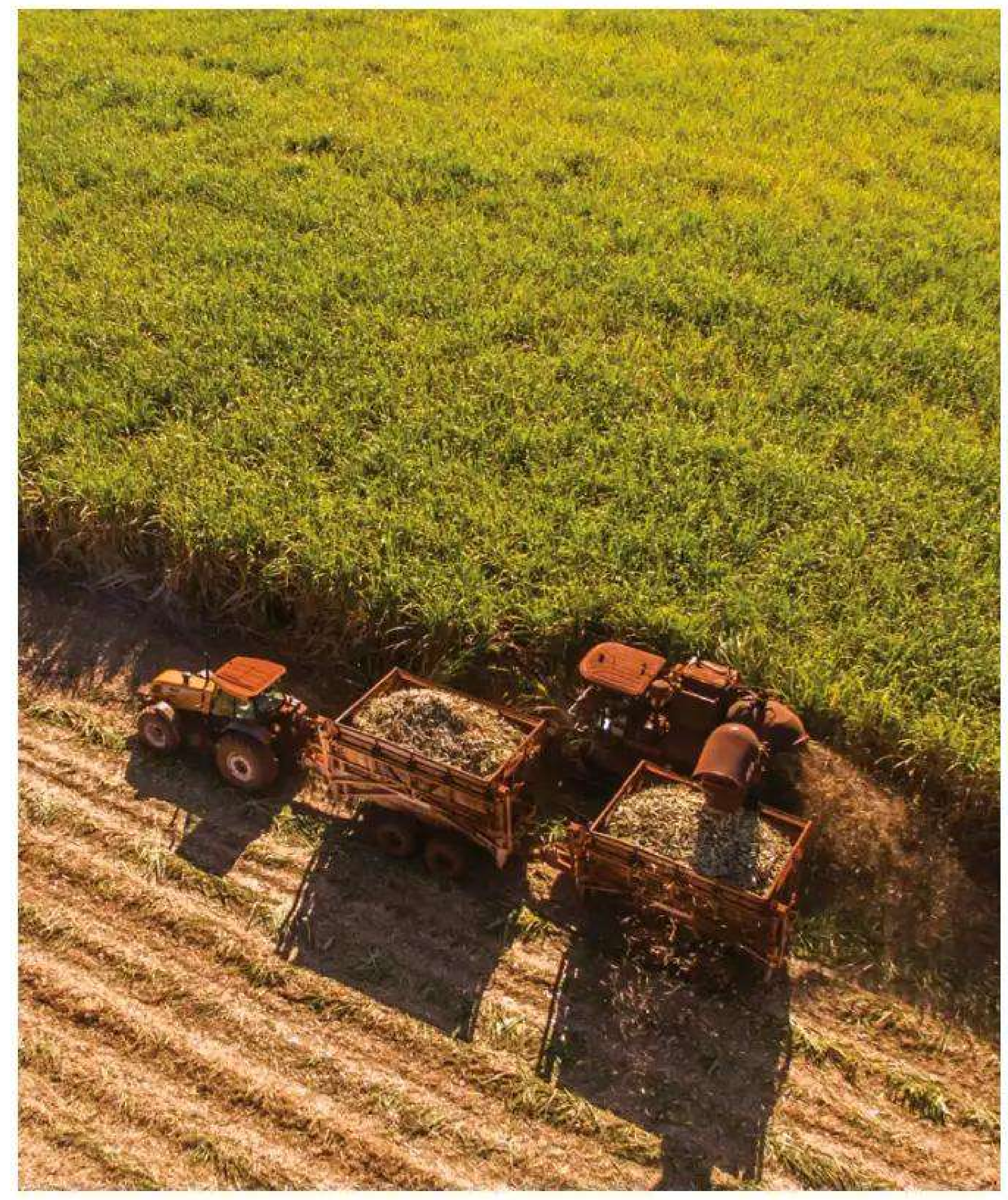
mistakes creep in. This creates tiny changes in the genetic code that pass to the next generation. For the most part the differences don't do anything useful – or harmful. The mutations are often silent (they do nothing) or neutral (they do something, but it doesn't make a difference). In fact, many mutations aren't even in genes; they're in the DNA that sits between them. However, sometimes mutations change the way a gene works.

New traits can also enter populations via gene flow. This happens when groups of people separate and then come back together, sharing new genetic information. Finally, traits change because of sex. Babies inherit genetic material from both parents, putting new combinations of genes together.

Over the past 100,000 years these three mechanisms have changed the traits that make us human, but we are still young in evolutionary terms. We take a long time to reproduce, and there's a limit to the amount of variation that can accumulate in a few hundred thousand years. Your genetic information only differs from mine by around 0.1 per cent, and most of those differences are single letter changes. Despite outward appearances, the whole human population still shares close family ties.

Our genes are always changing, but genetics is just one piece of the evolutionary puzzle. Our environment has a huge role to play in how our species evolves. For new traits to pass from generation to generation, they need to change our chances of survival. This is where Darwin's natural selection comes in. If a genetic change makes an individual more likely to reproduce they have a better chance of passing on their genes. We know this as 'survival of the fittest', but it's not always about being the biggest, strongest or fastest. It's about having traits that let you make the best use of your current environment. As the environment changes, so do the kind of mutations that might be useful.

This is where human evolution gets complicated. We can change our environment with culture, science and technology, messing with natural selection. If you look deep into history, our human-like ancestors were at the mercy of their environment. Lucy, a famous



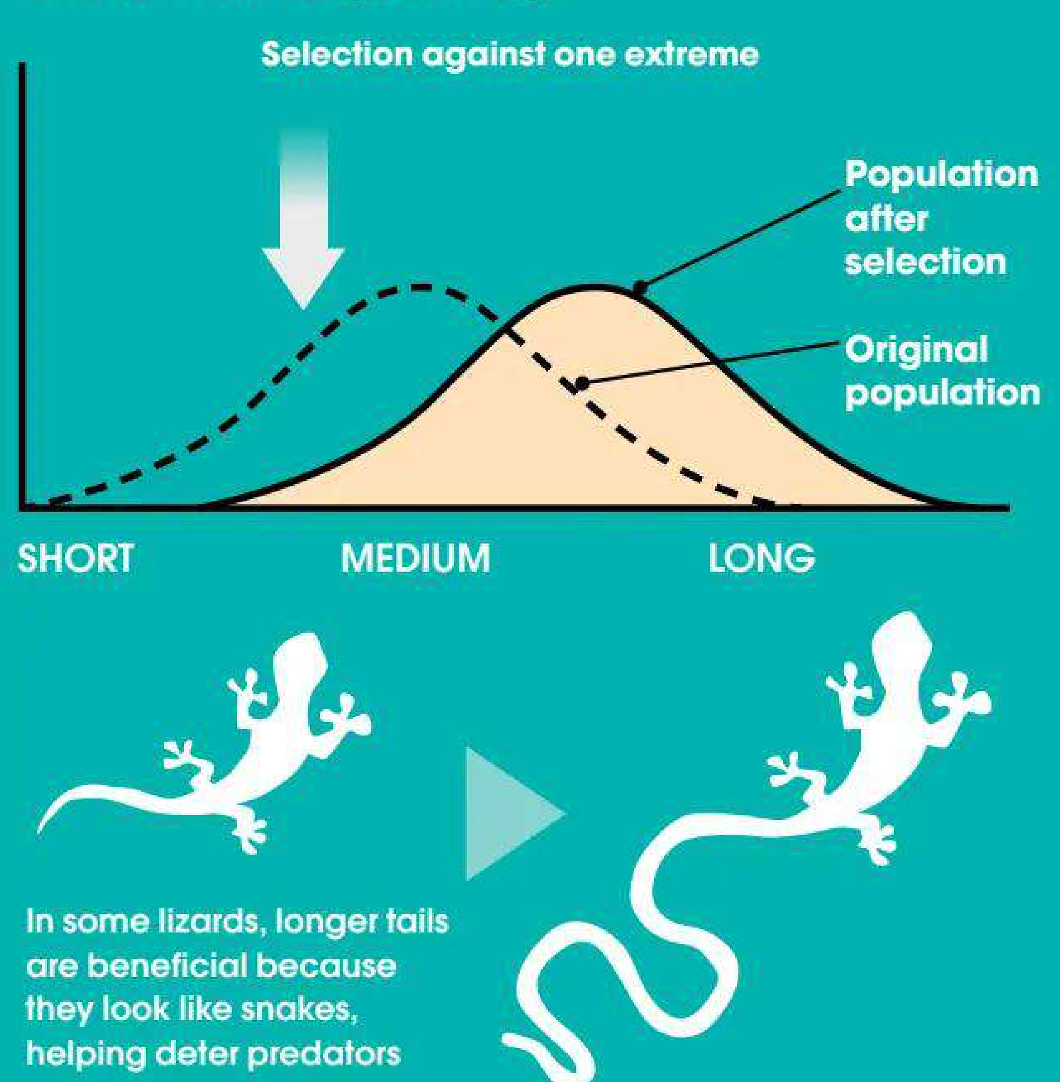
"As the environment changes, so do the kind of mutations that might be useful"

Types of selection

Three laws of natural selection govern evolution, but other selective factors can play a role

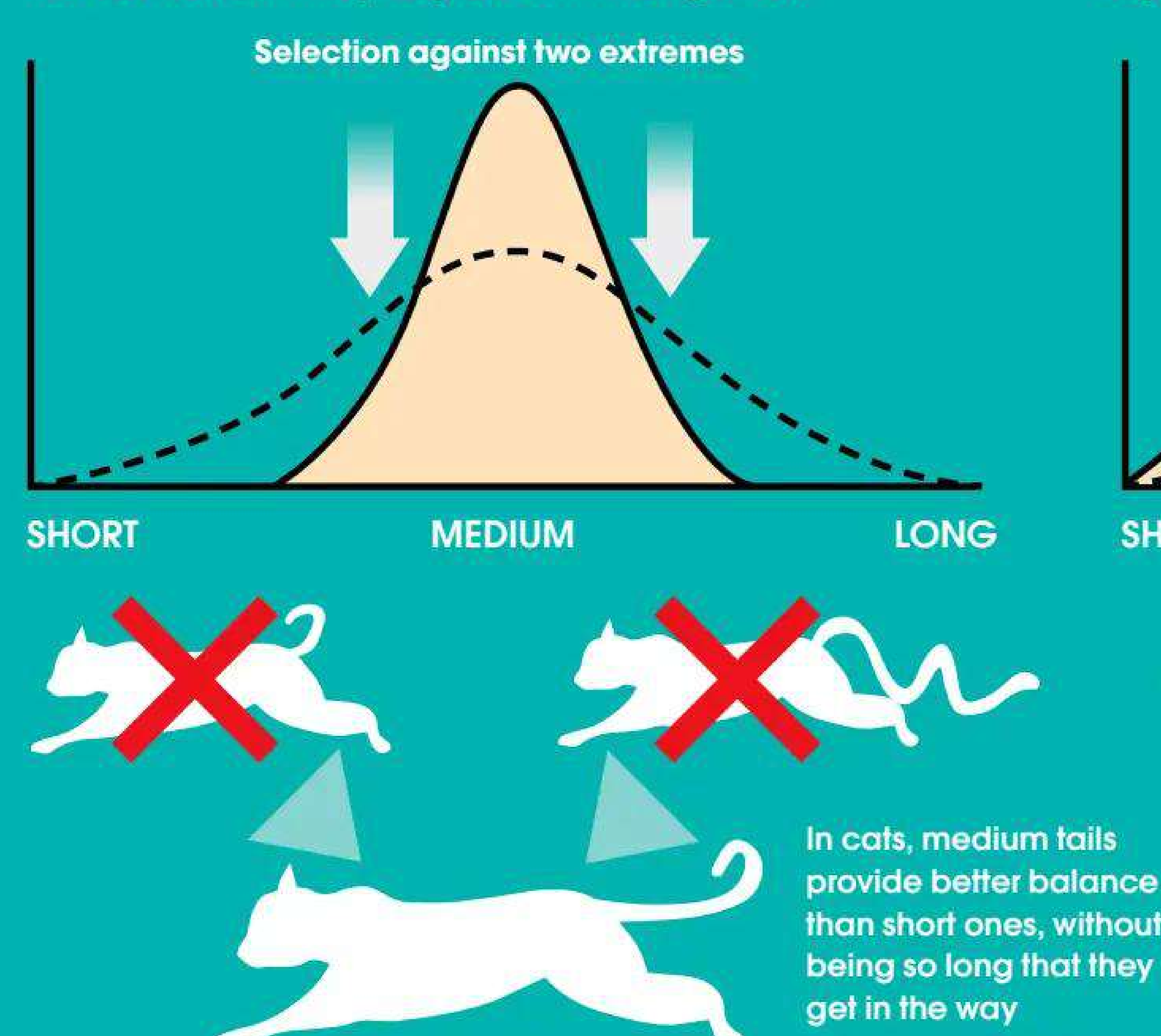
Directional

If the environment changes, it forces organisms to adapt. Directional selection pushes traits in one direction, towards a new solution. Once they find the solution, traits can stabilise again, unless the environment keeps shifting.



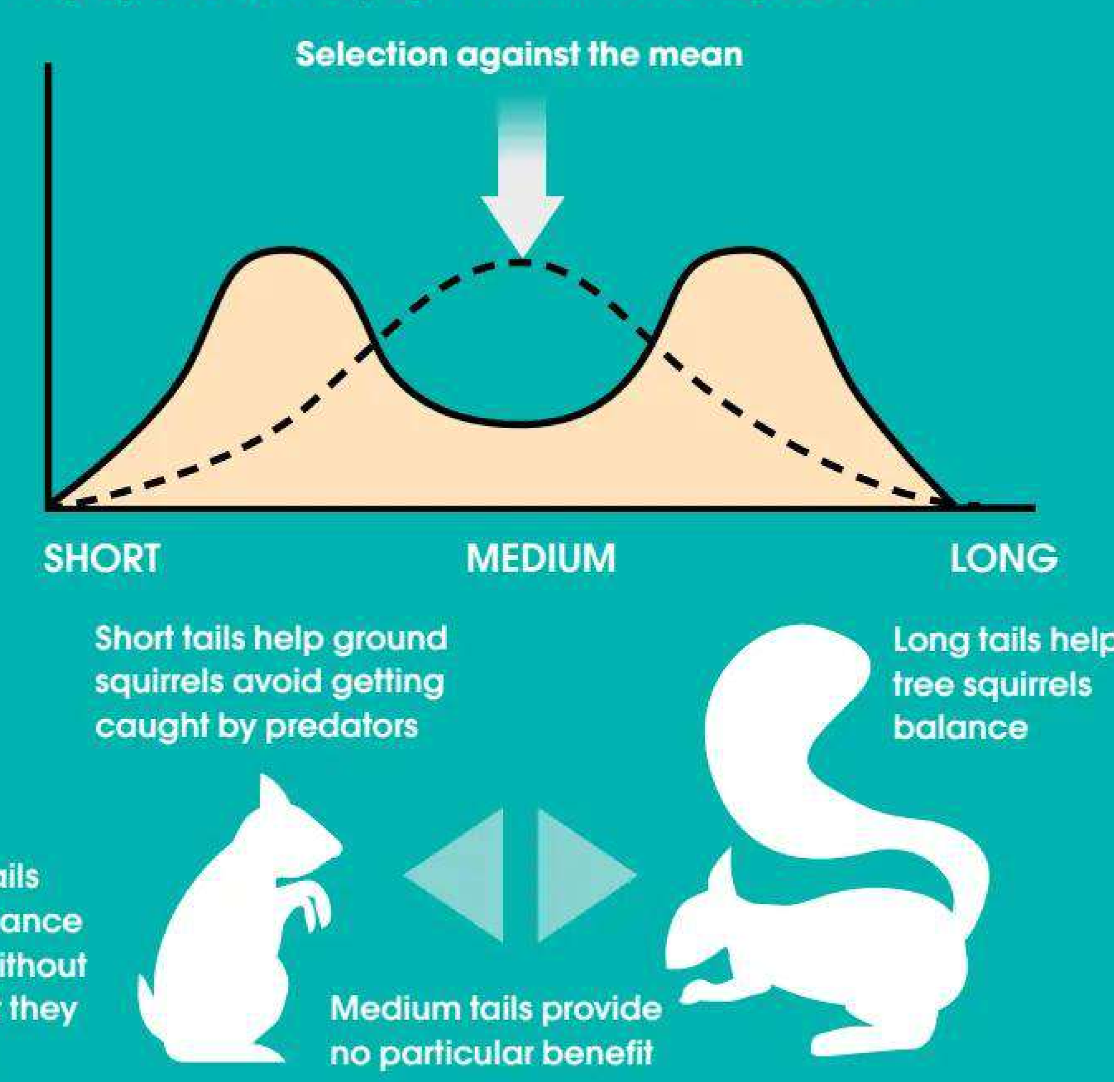
Stabilising

Stabilising selection encourages organisms to keep the same traits. This tends to happen when the environment is stable and the organism is already well adapted. Any changes make them less fit and therefore less likely to pass on their genes.



Disruptive

Sometimes there is more than one way to adapt to a change in the environment. In these situations organisms evolve away from the middle ground and towards one of two extremes. If this persists a population may split into two new species.



Sexual

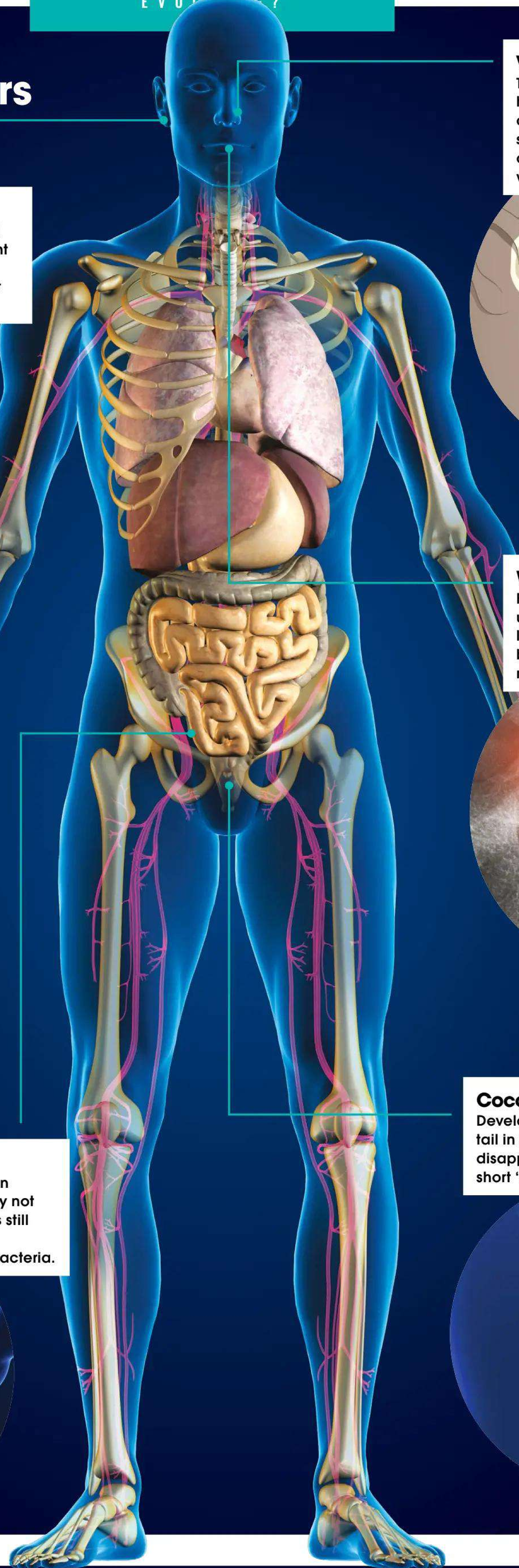
Natural selection favours animals best suited to their environment, but it's not the only way. Sexual selection favours traits that make individuals more attractive and more likely to reproduce, even if they don't help them to survive.

Artificial

Artificial selection works in the same way as natural selection, except that we make the decisions. By choosing which animals to breed, we dictate which traits are passed on to the next generation.

Evolutionary leftovers

Humans still carry some of the adaptations of our ancestors



Ear muscles

The three auricular muscles around the ears help cats and dogs to point their ears in the direction of noises. Some people can wiggle them, but they aren't much use to us.

Vomeronasal organ

This pheromone-sensing organ helps many animals to communicate using chemical signals. Most adults seem to have one, but whether it still actually works is unknown.

Wisdom teeth

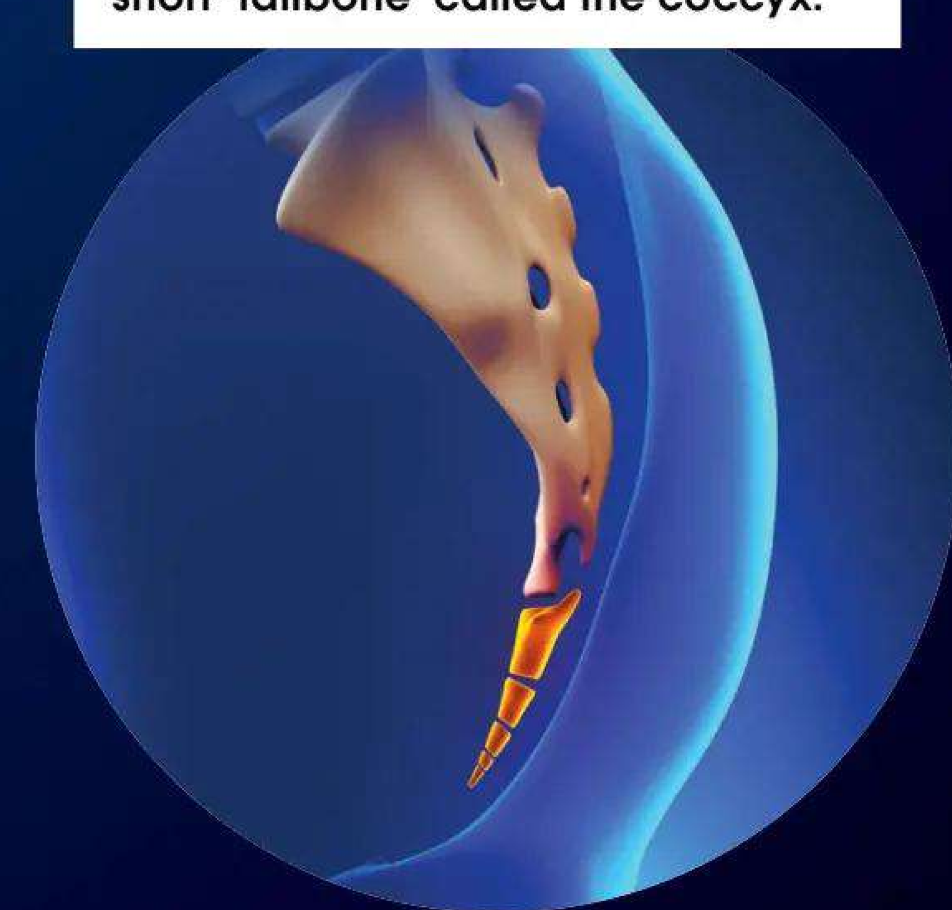
Four extra molars may have been useful to our ancestors, who had larger mouths and tougher diets, but we don't really need them any more. Some people don't have any.

Arm muscles

The palmaris longus muscles help primates to swing from trees, but we no longer need them. Most people still have short tendons, but in some people they are missing.

Coccyx

Developing human embryos form a tail in the womb, but it quickly disappears again, leaving behind a short 'tailbone' called the coccyx.



Appendix

Although we don't need an appendix to survive, it may not be completely useless. It's still thought to play a role in maintaining healthy gut bacteria.

fossil of a species known as Australopithecus afarensis, lived 3.2 million years ago. She had ape-like characteristics, including a large jaw, long arms and a covering of fur, but she walked on two legs. She lived in the trees like other apes, but the environment was changing – trees were disappearing, and Lucy was spending more time on the ground. Eggs found near her remains suggest she might have been foraging.

Between Lucy and mitochondrial Eve, climate change eventually forced our ancestors out of the forests and onto the plains. They had to run under blazing sunshine to survive, and body hair became a burden. Bare skin and the ability to lose heat by sweating became an advantage. Pressure from the environment pushed the genes of our ancestors to change.

Over time, early humans evolved bigger brains, smaller jaws and complex social structures. We harnessed fire and invented tools, and as we became more intelligent, we made more and more changes to our environment. This changed everything.

The advent of agriculture around 10,000 years ago caused a seismic shift in human history. Suddenly, we could produce our own food on demand, right next to our homes. DNA from ancient humans has revealed that changing our own environment changed at least 12 regions of our genetic code.

Researchers at Harvard Medical School examined the remains of 230 people who lived between 8,500 and 2,300 years ago. They found differences in genes involved in height, metabolism and skin pigmentation. Around 4,000 years ago, a mutation appeared that allowed adults to keep digesting milk. Light skin became more common, which the researchers believe may have been a response to less vitamin D in a plant-based farmer's diet. The immune system also changed, which may have helped people to live closer together.

We share behaviours that we learn during our lifetimes, passing information from generation to generation like genes. Learning and culture change our environment, changing the pressures that drive selection. This kind of genetic and cultural co-evolution isn't unique to humans. Whales and dolphins are some of the most intelligent animals on the planet, and there is evidence that they also evolve in response to learning.

Killer whales can tackle many different types of prey, but certain groups prefer different meals. In the North Atlantic, for example, some like salmon, some prefer mammals, and others eat sharks. These cultural preferences pass from mother to baby, and because the groups don't tend to mix, they stay the same across generations. Scientists found differences in the genetics of whales that eat fish versus those that eat mammals. We changed our genes by learning to farm, and they've changed theirs by choosing which prey to eat.

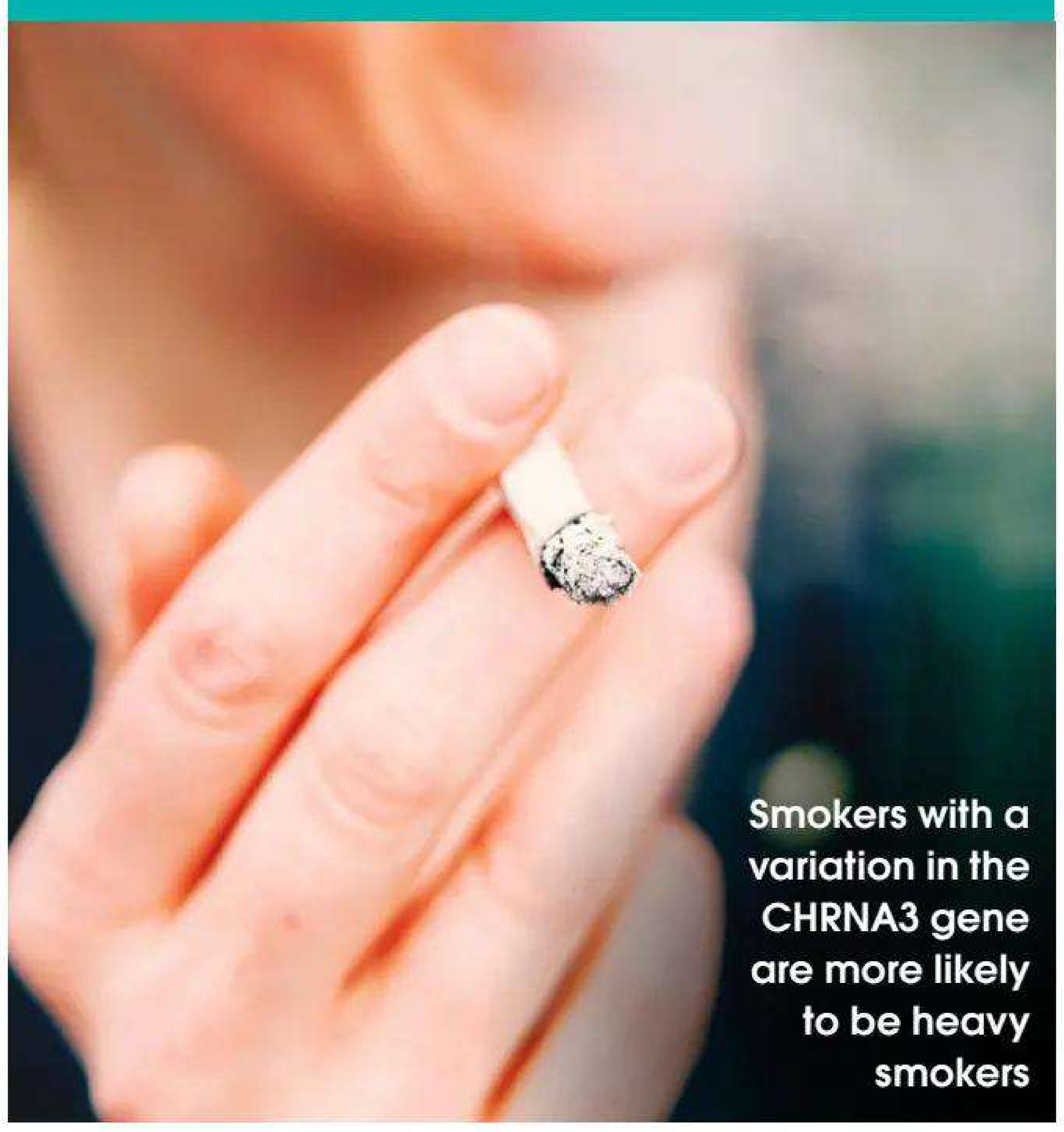
This cultural learning helps us to keep adapting, but humans have taken it further than any other animal. We made clothes and complex shelters. We domesticated plants and animals to provide a steady source of food. We built boats, cars and planes to explore the world. We invented medicine to treat injuries and disease. We made it possible to choose when – and if – to have children. We can

Ongoing evolution

Two recent studies have found evidence to suggest that we are indeed still evolving, albeit very slowly. Among smokers, those with a variant of a gene known as CHRNA3 are associated with smoking more heavily than average.

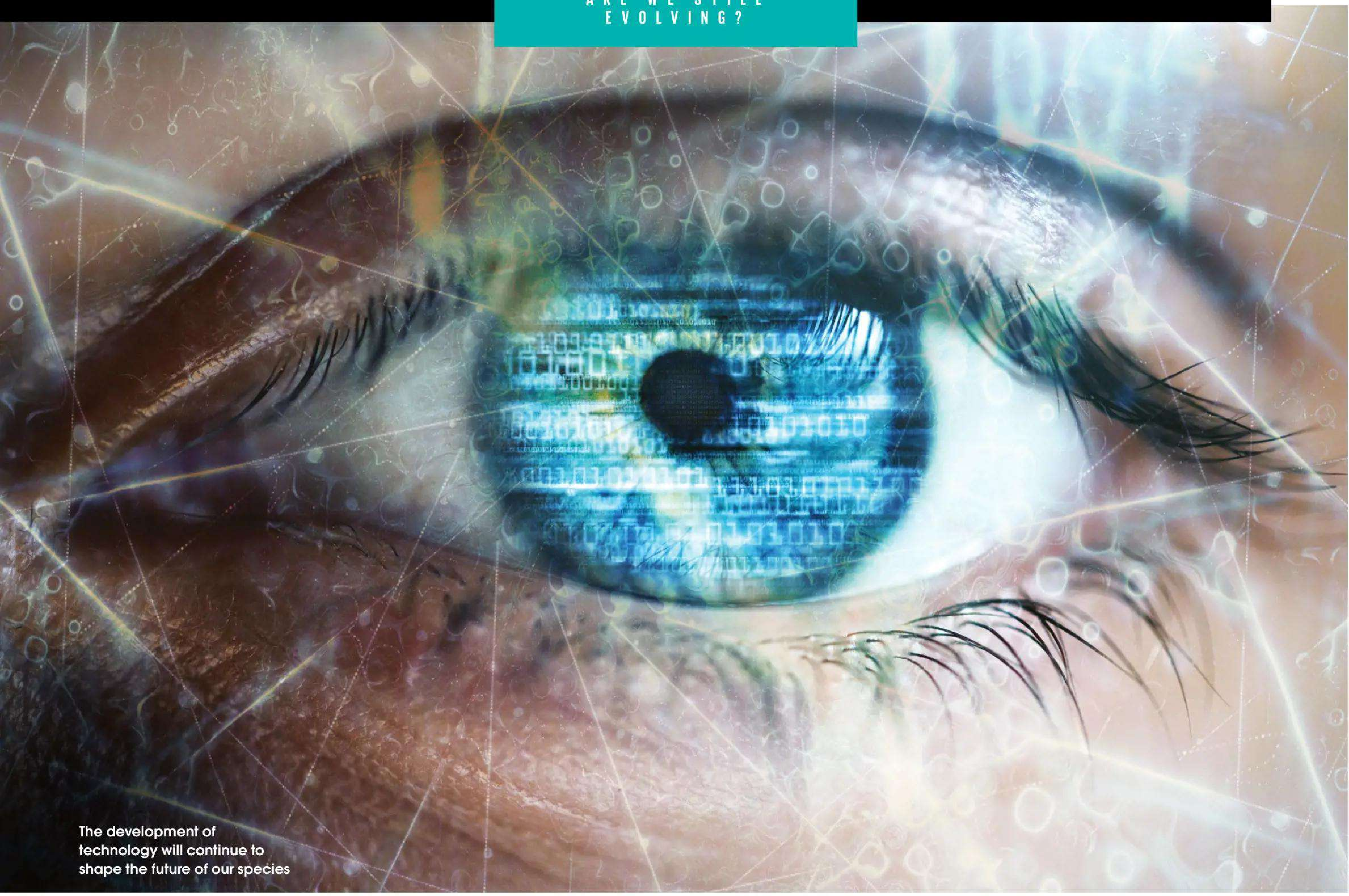
Being a heavy smoker increases the risk of dying from a smoking-related disease, such as lung cancer. Scientists found that, between generations of 80 year olds and 60 year olds, the variant of this gene has decreased by about one per cent. However, until further data is collected from the younger generations, this trend cannot be confirmed.

A similar decline seems to be emerging in those with a variant of the gene ApoE4, which increases the risk of developing late-onset Alzheimer's and cardiovascular disease. One possible explanation for both these gene variants becoming rarer is that more people are having children later. The number of people waiting until their 40s or 50s to start a family is increasing, but this is also the age at which people with such gene variants may be at risk of dying.

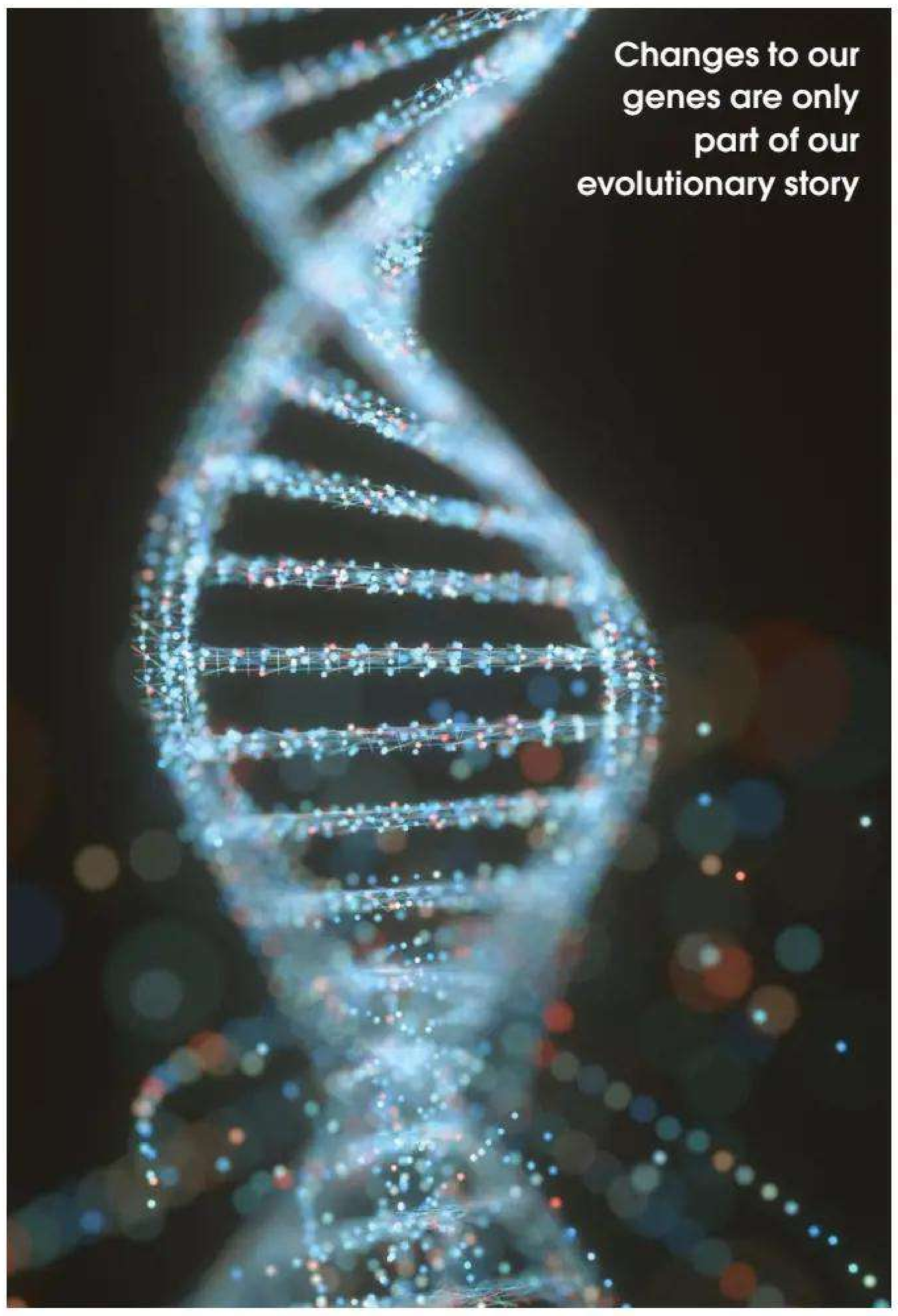


Smokers with a variation in the CHRNA3 gene are more likely to be heavy smokers

The jaws of humans and chimpanzees reflect our different diets



The development of technology will continue to shape the future of our species



Changes to our genes are only part of our evolutionary story

"Cultural learning helps us to keep adapting"

even survive in space. We have secured our environment, reducing the pressures that push other species to change over time. Reducing those pressures freed up even more time for new ideas and new technologies. Science has made it possible to change our environment more than ever before, but does that mean that we've stopped evolving?

It's hard to see evolution in action in human populations today because we have such a long lifespan, and even when natural selection isn't happening, our genes continue to mutate, a phenomenon known as genetic drift. However, there is one serious selective pressure that we still don't have under control: disease. If you look into its past you can see how modern humans have changed in recent years.

The plague ripped through Europe around 750 years ago, killing vast numbers of people. When our species faces diseases we can't yet treat, natural selection takes over. Scientists think that's why modern populations in Northern Europe have a higher frequency of a mutation in a gene called CCR5. This gene codes for a molecule used by the immune system, and it provides protection against the plague bacteria, Yersinia pestis. It also protects against the HIV virus. People with the protective trait were more likely to survive, and their descendants are still alive today.

As a species we have outsourced huge parts of our survival to technology. We control our environment to maintain a steady state, reducing the pressure that forces genes to change, but to keep this going we need our environment to stay the same, and we haven't worked it all out yet.

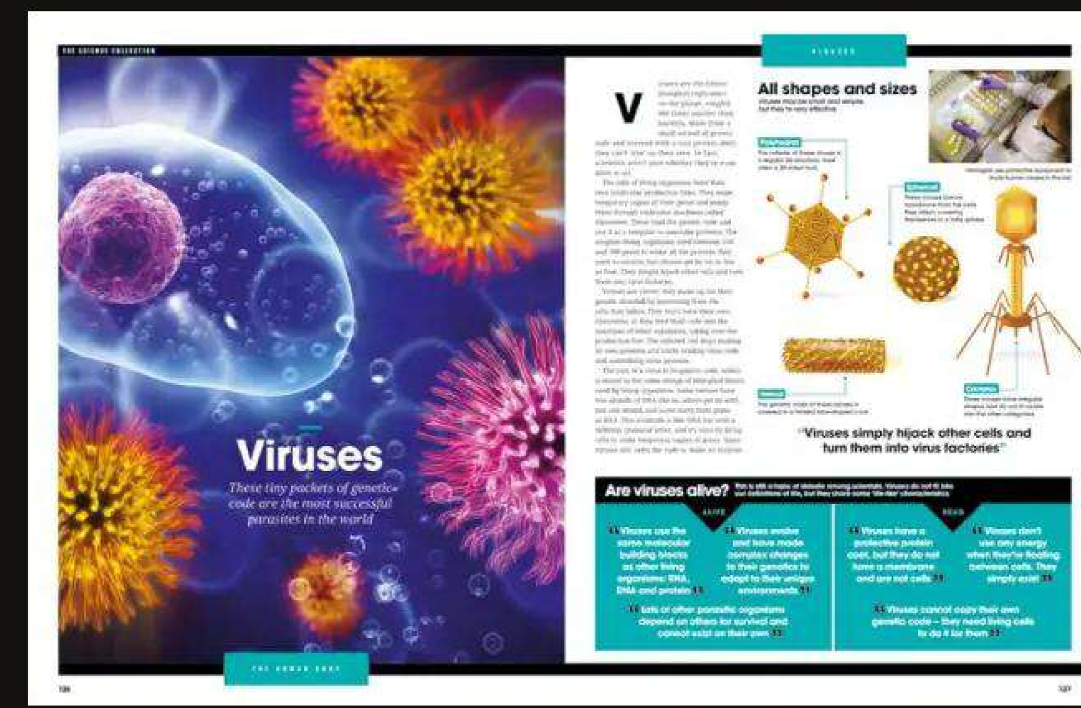
What happens when the climate changes, or when antibiotics no longer work as they should? We have buffered ourselves against natural selection for the moment, but we haven't out-evolved evolution.

SAVE THE WORLD

Find out how going green helps change things for the better

CRASH LANDINGS

What happens if we have 72 hours until an asteroid impact?



GOING VIRAL

The truth about viruses and how our bodies fight them

THE Science COLLECTION

9021

9000

BOOKAZINE